TRANSACTIONS

of the

American

Foundrymen's Association

Proceedings of the

Forty-Ninth Annual Business Meeting

Chicago, Illinois

July 18, 1945

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OFFICERS

of the

AMERICAN FOUNDRYMEN'S ASSOCIATION

(INCORPORATED)

(Fiscal Year Ending June 30, 1946)

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**Vice-President,* S. V. WOOD, Minneapolis Electric Steel Castings Co., Minneapolis, Minn.

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(In addition to the President and Vice-President)

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Headquarters, Room 1398, 222 W. Adams St., Chicago, Ill.

Secretary, WM. W. MALONEY

Treasurer, C. E. HOYT

Director, Technical Development Program, N. F. HINDLE

Assistant Treasurer, J. REININGA

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*Member of Executive Committee.

Program: 1945 Administration Congress

Palmer House, Chicago—July 17 to 19, 1945

From the time of the selection of Detroit as the 1945 Convention city, all necessary plans were made and progressed for holding a technical convention there on the dates of April 30-May 1. Early in January, however, the Office of Defense Transportation announced instructions on all wartime meetings involving more than 50 persons, and on January 17 the A.F.A. Board of Directors met and voluntarily canceled the Association's 1945 annual meeting.

Provision having been made for bringing to the membership the papers and reports scheduled for presentation at the canceled convention, it was decided to hold the Annual Business Meeting of the Association in Chicago on July 18, on an invitational basis and restricted to an out-of-town attendance of 50, at the time of the Annual Meetings of the Board of Directors on July 18 and 19. Decision also was reached to hold the 2nd Annual Chapter Chairman Conference on July 17-18, and to arrange all activities for the 3-day period July 17-19 as part of a "1945 Administration Congress."

Chapter Chairman Conference

July 17 Morning—Chapter Chairman Conference.

July 17 Afternoon—Chapter Chairman Conference.

July 17 Evening—Chapter Chairman Conference Dinner.

July 18 Morning—Chapter Chairman Conference.

July 18 Noon—Joint Luncheon of Chairmen and Directors.
Joint luncheon between delegates to the Chapter Chairman Conference and the National A.F.A. Board of Directors.

Annual Meeting, 1944-45 Board of Directors

July 18 Afternoon—Annual meeting of 1944-45 Board of Directors.

Annual Business Meeting of A.F.A.

July 18 Evening—Annual Business Meeting of A.F.A.
Dinner meeting, 7:00 PM. This meeting held in lieu of the Business Meeting ordinarily held at the time of the Annual Convention. Business included announcement and presentation of newly elected Officers and Directors, awards of Medals and Honorary Life Memberships, announcement of Apprentice Awards and a digest of the 1945 Foundation Lecture by Dr. H. A. Schwartz.

Annual Meeting, 1945-46 Board of Directors

July 19 Morning—Annual meeting of 1945-46 Board of Directors.

July 19 Afternoon—Annual meeting of 1945-46 Board of Directors.

Summary of Annual Business Meeting

Palmer House, Chicago — July 18, 1945

PRESIDING

National President of A.F.A., Ralph J. Teetor

Introductions . . . . . President R. J. Teetor
Introducing the National Officers and Guests seated at the Speakers' Table, and the Chapter Officers and Guests attending the 2nd Annual Chapter Chairman Conference of A.F.A.

President's Annual Address . . . . . President R. J. Teetor

Presentation of
Honorary Life Membership in A.F.A. . . . . By L. C. Wilson
Chairman, Board of Awards
To A. H. Van Keuren, Rear Admiral, U.S.N., Director of Naval Research Laboratory, Washington, D. C. . . . *"in recognition of his efforts in behalf of the Foundry Industry."*

Presentation of
Honorary Life Membership in A.F.A. . . . . By L. C. Wilson
To M. J. Gregory, retired, past Director of the Association . . . *"for his contribution to the Association and the Foundry Industry."*

Results of
1945 National Apprentice Contests . . Secretary R. E. Kennedy
Announcing the winners in the Annual Apprentice Contests of A.F.A.—in Gray Iron Molding, Steel Molding, Brass and Bronze Molding, and in Patternmaking.

Presentation of
John A. Penton Gold Medal of A.F.A. . . . By L. C. Wilson
To Clarence Edgar Sims, Supervising Metallurgist, Battelle Memorial Institute, Columbus, Ohio . . . *"because of his outstanding contribution to the Steel Casting Industry."*

1945 Foundation Lecture
By Dr. Harry A. Schwartz, Manager of Research, National Malleable & Steel Castings Co., Cleveland. A digest of His Foundation Lecture on *"Solidification of Metals,"* presented by F. G. Sefing, International Nickel Co., New-York, in the absence of Dr. Schwartz.

Presentation of
Joseph S. Seaman Gold Medal of A.F.A. . . By H. S. Simpson
To Robert Edwin Kennedy, Secretary of A.F.A. . . . *"for outstanding meritorious service to all branches of the Foundry Industry through his work in organizing and guiding the development of technical and operating papers and discussions, and his untiring encouragement to all A.F.A. Chapters, committees and members."*

Presentation of
Honorary Life Membership in A.F.A. . . . . By L. C. Wilson
To Ralph J. Teetor, retiring President of the Association.

Presentation of Newly Elected
National Officers and Directors of the Association
Announcement and presentation of new Officers and Directors, elected in accordance with the Association's by-laws:

President, Fred J. Walls, International Nickel Co., Detroit.

Vice-President, S. V. Wood, Minneapolis Electric Steel Casting Co., Minneapolis.

Director, G. K. Dreher, Ampco Metal, Inc., Milwaukee.

Director, E. W. Horlebein, The Gibson & Kirk Co., Baltimore, Md.

Director, H. H. Judson, Goulds Pumps, Inc., Seneca Falls, N. Y.

Director, F. M. Wittlinger, Texas Electric Steel Casting Co., Houston.

"Castings and the Post-War Industry"
Speaker: Max Kuniansky, Vice-President and General Manager, Lynchburg Foundry Co., Lynchburg, Va.

President's Annual Address

By Ralph J. Teetor,* Cadillac, Mich.

WHEN, in January, the Director of War Mobilization requested that conventions be canceled except those involving distant attendance of less than 50 persons, your Board of Directors was quick to respond and to cancel plans for the 4th War Production Foundry Congress, which had been scheduled for the first week in May and for which extensive preparations had already been completed. Thus the 49th Annual Convention of A.F.A. became a war casualty, but this 49th Annual Business Meeting survived.

Cancelation of the convention necessitated the undoing of many things that had been planned, foremost of which was preparation for the Pre-Convention issue of American Foundryman. Space had been sold and advertising matter prepared, when it became obvious that a Pre-Convention number without a convention could hardly be justified.

New Magazine Policy

Immediate decisions became necessary. On January 16, the Executive Committee met, and on the following day the Board of Directors. It was unanimously decided to abandon plans for the 49th Annual Convention in Detroit and to adopt a suggestion which had been discussed and urged many times in past years—to include advertising in each issue of American Foundryman, beginning in May and carrying on during the rest of 1945, and to present a "Year-'Round Foundry Congress," through its pages.

Consequently, you now have the American Foundryman in its new form. Decision as to whether the policy of continuing its present form after the trial period, has yet to be made.

The constantly improved pages of the American Foundryman keep our membership more completely informed of the progress of the Association and of the actions of the Board of Directors. The "Report to the Membership," recently sent to all members from the National Office, enumerates the major activities which have been completed or are presently in progress or about to be undertaken.

At this time I wish to mention a few of the accomplishments of A.F.A. which I consider especially noteworthy and as having progressed or been initiated during the past year.

New Membership Record

Membership has again reached an all-time high, standing at 7,815 on June 30, 1945. The significance of this accomplishment is obvious. Your Technical Staff and the General Staff at the National Office, as well as your National Officers and Board of Directors, are fully aware that this increasing interest in the objectives of the Association creates an obligation for the enlargement and amplification of the services which may properly be offered by the Association.

National Membership Chairman Fred Walls and his committee of Chapter membership chairmen are entitled to all the credit for the more than normal increase in membership during the past year.

Company and Sustaining Dues Raised

A committee of the Board was appointed to thoroughly explore the matter of dues from members, and brought in the recommendation that Company Member dues be increased from $25.00 to $50.00 annually, and that Sustaining Membership dues be increased from $50.00 to a minimum of $100.00 annually. No recommendation was made for a change in the dues of Personal Members. The recommendation of this subcommittee was unanimously approved by the Board of Directors in January, and the new dues structure therefore became effective on July 1 of this year.

Four Chapters Added

Expansion of our Chapter Membership by four new Chapters—Central Ohio, Oregon, Saginaw and Northwestern Pennsylvania—is an accomplishment in which your National Officers take great pride. Credit for this outstanding achievement goes three ways: to Secretary Robert E. Kennedy, who has so effectively promoted and encouraged Chapter organization; to the local committees of foundrymen, members of A.F.A. who have assumed the burden of organizational work; and to the neighboring Chapters who have cooperated so generously and have in some cases given up a portion of their own membership in order that new Chapters in other areas might be established.

Acquisition of the Dr. Richard Moldenke Library of some 500 volumes on foundry practice in America and abroad, the gift of Mrs. Moldenke, constitutes a notable addition to the library of A.F.A., which is now the most complete collection of text books on foundry practice in America. One of the major objectives of the Association, and one of increasing interest and importance, is to expand our technical library and promote its availability to foundry and related interests.

How T.D.P. Began

I want to say a special word here about the Technical Development Program, because, while it has begun to reach sizeable stature during my term of office, it had its conception in the minds of earlier administrations several years back. Definite action was taken toward establishment of an A.F.A. Foundation under the leadership of past President Duncan Forbes, in 1942-43. That administration made no mistake when it envisioned a Foundation for the advancement of foundry science, greater in scope and requiring greater financial outlay than has as yet been found possible of fulfillment.

During the succeeding year, 1943-44, your Board of Directors under the leadership of Lee Wilson considered

*President, Cadillac Malleable Iron Co.

Note: Presented by retiring President R. J. Teetor before the Annual Business Meeting of A.F.A., July 18, 1945.

and reconsidered, revamped and reconstructed, and even renamed the project. By the end of that year they had formulated a revised plan, now the Technical Development Program, which gives promise of carrying out the fundamental objectives earlier envisioned, and of growing to the stature originally conceived.

The Technical Development Program has completed its first year of existence under the directorship of Norman F. Hindle. It has taken over the publishing of technical books on foundry practice and has functioned well, within the limits of personnel and time available.

Unlimited Possibilities

It is to be expected that the Technical Development Program, having as its functions the promotion of technical publications, expansion of library facilities and the encouragement of increasing educational opportunities as related to the foundry industry, will make itself felt and increasingly valuable, as the ambitious program which it has undertaken gradually develops. Plans are definitely under way for the expansion of its technical and administrative personnel, necessarily difficult of accomplishment because of conditions arising out of the war.

Technical development activities constitute the most important function of a technical society such as A.F.A., for without expanding technical activities and promotion of technical education opportunities and facilities for the foundry and allied industries, this great Association of ours would take on the color of a social or fraternal organization.

The support that has been given to the financial requirements of the Technical Development Program has been generous. It is to be expected that, as this program expands and is more fully recognized in its true perspective, the membership of A.F.A. and the foundry and allied industries will continue to support it even more liberally.

Relations with Trade Groups

Another field in which A.F.A. offers service to the foundry industry is in cooperation with the several foundry trade associations which serve the various branches—steel, malleable, gray iron, nonferrous. In promoting the commercial advancement and technical progress of the various industries, these trade associations are great constructive forces in the industry; but they are by their very nature separately inspired and functioned.

The foundry industry will present to industrial America a more accurate conception of its basic importance when there is greater unity in the objections of the various branches. The most wholesome and permanently constructive objective looking toward unity of purpose and deserving of national recognition stands unchanged for 49 years;

> "To promote the arts and sciences applicable to metal castings manufacture. To improve the methods of production and quality of castings."

Within this premise, A.F.A. eagerly solicits every opportunity to be of service to every Trade Association of the foundry or allied industry. The A.F.A. can never divert its energies from this single purpose. It can never assume the general functions of a trade association. It can, however, through the expansion of its membership and through its more comprehensive services to members, promote the unification of the foundry industry and national recognition so well deserved.

A Mandate for Service

A technical society whose membership has expanded from 2,500 to 7,800 in the space of eleven years, and whose increment of increase has quite generally been greater year by year (1,195 in the last twelve months), surely has received a mandate to expand its services.

Now in closing, I wish to say a word of appreciation to the staff at the National Headquarters. The servicing of our greatly increased membership, our expanding chapters, now numbering 31, and the promotion of activities under the Technical Development Program has been accomplished through the fine and loyal efforts of the staff organization.

As my term of office comes to an end with this meeting, I find it impossible to adequately express my appreciation to the many committees of the Association for their splendid work throughout the year, to those authors who have prepared the papers now being published in the AMERICAN FOUNDRYMAN in lieu of the Convention, to the Directors, and especially to the members of the Executive Committee for their fine support and cooperation.

My principal regret is that I found it utterly impossible to take advantage of the privilege of visiting many of the chapters during my term of office. Such visits as I could and did make were inspiring to me and will always remain among my most pleasant memories. I deeply appreciate the honor of having been called upon to serve.

Presentation of The Joseph Seaman Gold Medal Award to Robert E. Kennedy

By H. S. Simpson, Past President and Member of the Board of Awards
At the ANNUAL BUSINESS MEETING, Chicago, July 18, 1945

IT IS a real pleasure to me to present the Joseph Seaman Gold Medal to Bob Kennedy because of the sincere respect that everyone in the foundry industry has for him. I could speak endlessly on his many good points. I don't know of any man, in or out of the foundry industry, who is more conscientious, less selfish, and who really wants to do things for other people more than does Bob Kennedy. He has a wonderful character and disposition and has been a tremendous help to the foundry industry as a whole and particularly to all the members of the American Foundrymen's Association, with which he has been connected for so long a time.

Bob Kennedy's first full-time job was when he was a student in grade school in Vincennes, Indiana. This job was in a cigar factory where he was the chief "stripper." A "stripper" pulls the stems out of cigar leaves. It was there, as Bob says, that he tried his first tobacco chewing and soon stopped, which he also remarks was not a good start for a foundryman or a molder. Then he went to the Winona Trade School, where they were doing commercial work for foundries of that district. He was paid the magnificent sum of four cents an hour (there were no unions at that time), and later during the depression of 1907 he worked for no cents ($0.00) per hour; in fact, he earned his living by washing dishes and tending furnaces. He remarks that food was a problem, so very often he would get some hot dogs and fry them over the core oven fire, until he found one restaurant where he could get all he wanted for 25 cents. Imagine how different it is at the present time. His experiences learning to become a foundryman were interesting and he has never forgotten the things that he got the hard way.

His first American Foundrymen's Association Convention was in 1910 at Detroit. At that time he was a student at the Winona (Indiana) Technical Institute, where several of the boys were learning to be foundrymen. Some way they found an opportunity to go to Detroit and were immediately impressed with the magnitude of the foundry industry, and also, as Bob says, were astonished at the kindness of the older men who greeted them. They all tried to be helpful, so the boys went back to their school with a feeling of importance and pride in our industry. How essential that is at the present time when all foundrymen should have the same feeling for young men who are, or should be, interested in the foundry industry. Bob joined the Association that same year—1910—so, of course, he is an old timer in the A.F.A., dating back 35 years, three and one-half decades.

His first paper before the American Foundrymen's Association was in 1914, when he discussed some information that he had obtained in making time studies on molding methods. The second paper was in 1915 on core room practices. As a result of that second paper he states that he will never forget some of the criticism he had, but most of the comments were complimentary; after all, he was young and was learning what to say and what not to say.

Meanwhile, Bob went to the University of Illinois in the fall of 1909 taking a mechanical engineering course. He then was offered the position of instructor in foundry practice, which he took and handled very well as everyone in those days had a great deal of respect for the ability that he showed in connection with his job.

Later in 1916 he contributed a paper at the Cleveland Convention of the A.F.A. on the subject "Analyzing Foundry Operations as a Basis for Improvement in Shop Conditions." This paper with illustrations and graphs will be found very interesting to anyone who will study it even at this time.

Bob's final contribution before coming with the American Foundrymen's Association was at the 1920 Convention when, together with Bruce Benedict of the University of Illinois, Bob presented a paper on the subject "Training Foundry Executives." This also appears in the A.F.A. Bound Volumes and it, too, will be found a valuable study at this date. At that time, our old friend, A. O. Backert, past President of the A.F.A., started an interesting discussion of Bob Kennedy's paper. We quote from Mr. Backert: "Mr. Kennedy and Mr. Benedict are to be highly commended for the marvelous work they have undertaken at the University of Illinois. For many years I have heard foundrymen criticise the efforts that are being made by colleges and schools in endeavoring to train apprentices, to turn out shop executives, and in some experimental cases to turn out molders. In very few instances have the foundrymen lent their financial support although they always had plenty of so-called moral criticism. I think the time has come when the foundrymen of the United States must get back of some movement, not only morally, but get back of it financially to help train executives that are so sorely needed in the foundry industry today." Timely advice from Mr. Backert.

Isn't it rather significant that Mr. Backert at that time would discuss a matter that is even more important today and needs just as much attention now as it did then? Of course, Bob Kennedy has in these many years done everything that anybody could do to help along the laudable project of training men for the foundry industry. If the paper presented didn't do more than to provoke such comments and bring them to the attention of the foundrymen of the country, it was certainly of real value.

His friend, Charlie Hoyt, recalls sitting in the Colosseum at the State Fair Grounds at Columbus and hearing Bob's paper and the discussion which followed.

Bob Kennedy had served on the papers committee in 1916 when Cole Estep was chairman, and it was his service on that committee plus the contributions mentioned above that prompted Mr. Hoyt, when he had received authorization for securing an assistant secretary, to go down to Urbana in 1921 and get Mr. Benedict's permission to approach Bob Kennedy with an offer, which resulted in securing him for the American Foundrymen's Association. Mr. Hoyt, incidentally, considers this his most valuable contribution during his 36 years' activity with the Association.

Bob Kennedy's industry record appears in the March, 1945, issue of the AMERICAN FOUNDRYMAN, which mentions the experience he obtained during World War I in the Steel Foundry of the Watertown Arsenal, Watertown, Mass. Mention also is made there of the fact that he was honorably discharged from the Army in 1919. He then was made Assistant Superintendent of the U. S. Training Service, Foundry Training, Department of Labor, where among other things he prepared the bulletin on industry training. He then returned to the University of Illinois as superintendent of the foundry where he was negotiated for by the A.F.A. and started his services with our Association in 1921. Bob then carried on his work as assistant secretary and later as technical secretary while he was still active at the University of Illinois, commuting back and forth between Urbana and the Chicago office of A.F.A. until in 1928 he moved to Chicago and from that time to this, he has given his full and valuable service to the American Foundrymen's Association—twenty-four years with A.F.A.

It is almost unnecessary to outline what he has done from 1928 to 1945 for the A.F.A., including the last few years when he has been Executive Secretary. His work on chapters, his acquaintanceship and cooperation with all of the hundreds of

committeemen, his organization of papers at conventions and his loyalty to the A.F.A. has been a record that I think may never again be equalled. Bob Kennedy is one of those men who thinks more of his job and of the Association that he has worked for for so many years, than he does of himself. He has done his work regardless of what it meant to him personally. When I think of all the men in the country who deserve a medal and recognition of that kind from the American Foundrymen's Association and from the industry in general, it is certainly Bob Kennedy, who is one of the first on the list.

It is, therefore, a great pleasure for me, representing the Board of Awards, to present the Joseph Seaman Gold Medal to Robert E. Kennedy for his work in the Foundry Industry and for the American Foundrymen's Association. The theme for the Seaman Medal is kindliness—doesn't that truly characterize our Medalist? All of us wish him the best of luck, continued work in the thing he likes to do best, and to let him know that this medal is not only for the valuable work he has done but also as a token of affection and esteem from all of those who know him. God bless Bob Kennedy.

R. E. Kennedy's Reply to H. S. Simpson's Presentation

I feel especially humble upon receiving this medal, because I know what the Board of Awards has had in mind over the years when bestowing this honor, and I know my unworthiness in meeting this standard. Certainly, I am greatly and deeply appreciative of this award.

In accepting this medal, I do so with the clear understanding that whatever I may have done has been solely due to the diligent and valuable work of our authors and committee and chapter workers. They are the ones to whom I feel this honor should be given. I can realize perhaps better than others how freely these men have given of their time, experience, and knowledge. The record of the A.F.A., as published in the Transactions, shows that the books and reports of the Association are truly monumental and are expressive of what we have come to accept as the A.F.A. motto:

"Coming Together is the Beginning;
Keeping Together is Progress;
Working Together is Success."

This has been the watchword and accepted policy of the A.F.A. since its organization in 1896, nearly 50 years ago when farsighted pioneer men of the industry gathered together at Philadelphia to organize the A.F.A.

As a schoolboy I attended my first convention at Detroit in 1910, and there I was deeply impressed by the universal and kind helpfulness to a group of schoolboys of those of the industry attending that meeting. This attitude has always impressed me as the outstanding characteristic of men of the industry, men with whom I have worked and grown to love for their kind helpfulness and cooperation, with all working together to solve the problems of the industry. This attitude I know will always be a foremost characteristic of the men of the casting industry. I recall with pleasure certain men who have been most helpful to the A.F.A. and to my work as a member of the Staff—Hy Bornstein, Jim MacKenzie, Dr. Moldenke, and then John Bolton and the later group of our present workers. I feel especially proud to have had a little influence in encouraging some of these workers, especially Harry Dietert, who I feel is my protege, inasmuch as I introduced him to our original Committee on Foundry Sand Research.

In accepting this honor, I want to acknowledge most freely the leadership of Ed Hoyt and the cooperation of our Staff, especially Jennie Reininga, Norm Hindle, Bill Maloney, and others.

Mr. Simpson, it is an honor to accept this medal from you, a member of the Board of Awards, who represents all that the A.F.A. stands for, and I thank you and the Board for thinking of me as worthy, and it is with every hope that I may continue to be helpful in the future and show that kindliness which was an outstanding characteristic of "Daddy Seaman," the donor of this award.

Presentation of the John A. Penton Gold Medal Award to Clarence E. Sims

By Lee C. Wilson, Past President, A.F.A.

The opportunity of making the presentation of the John A. Penton Gold Medal awarded to Clarence E. Sims this year by the Board of Awards gives me unusual pleasure. I am familiar with a number of the many worthwhile scientific investigations which he has made over the years to the benefit of the Foundry Industry. He has drawn unstintingly upon his knowledge to help solve problems of foundrymen in order to help make a better industry.

Born in Chicago, Mr. Sims received his early education there. Later he attended the University of Illinois, from which he was graduated in 1915 with a Bachelor of Science degree in Chemical Engineering. He continued his studies at the University of Utah and received his Master of Science degree the following year. He then entered industry and served in various capacities with the Anaconda Copper Mining Company, Anaconda and Great Falls, Montana; Michigan Electrochemical Company, Menominee, Michigan; R. W. Hunt Company, Chicago, Illinois; Research Division, Chemical Warfare Service, Washington, D. C.; Aluminum Co. of America, Niagara Falls, N. Y.; U. S. Bureau of Mines Experimental Station, Seattle, Washington and Pittsburgh, Pennsylvania; American Steel Foundries, East Chicago, Indiana. Early in 1936 he took his present position with the Battelle Memorial Institute.

Mr. Sims has written widely for the technical press on subjects such as Melting Units and Methods, Heat Treatment, Synthetic Cast Iron, Refractories and Inclusions. In 1932 Clarence Sims was co-author with G. A. Lillieqvist of a paper on "Inclusions—Their Effect, Solubility and Control in Cast Steel," which was presented at the meeting of the American Society of Mining and Metallurgical Engineers, which won for them the R. W. Hunt award for the best paper on iron and steel presented before that organization in that year.

Clarence E. Sims is a past director of American Foundrymen's Association and has been long active in the technical work of the Association, having presented numerous papers and served on many committees. He is also active in the new Central Ohio Chapter of the Association. He is a member and chairman of the Committee on Methods of Producing Steel for Castings and is A.F.A. representative on the Open Hearth Committee of the Institute of Mining and Metallurgical Engineers.

Clarence Sims has presented before American Foundrymen's Association meetings papers on the "Preparation of Steel to Avoid Porosity in Castings," "Effect of Aluminum on the Properties of Medium Carbon Cast Steels" and "Hydrogen and Nitrogen as Causes of Gassiness in Ferrous Castings," the latter in collaboration with C. A. Zappfe.

From a practical standpoint his work on the "Preparation of Steel to Avoid Porosity in Castings" and "Effect of Aluminum on the Properties of Medium Carbon Cast Steels" have been most outstanding in their benefits to the manufacturer of steel castings and have been the direct means of helping many steel foundries in eliminating porosity, particularly in pressure castings.

It is therefore my privilege to present to Clarence E. Sims, Supervising Metallurgist of Battelle Memorial Institute, the John A. Penton Gold Medal of the American Foundrymen's Association in recognition of his outstanding contributions of scientific and practical value to the Foundry Industry and to this Association.

C. E. Sims' Reply to L. C. Wilson's Presentation

In replying, I wish first to say simply and honestly that I am deeply honored. In thanking the Board of Awards and the Board of Directors who chose me for this honor, I would like to add that my greatest personal satisfaction comes from the realization that I have friends who think well of me. Mr. Wilson has been most kind in his remarks, but if it is true, as he says, that I have made some small contribution to the advancement of the steel casting industry, then much credit must be given to the fact that I have had unusual opportunities. Facilities and time have been made available to me, by farsighted men who believe in research as a practical activity. I have also been fortunate in being associated with co-workers who have been a source of inspiration and help. I accept this award with the understanding that it is something much more than a personal tribute, it is a recognition and an appreciation of the spirit of progress that today is permeating all of our industry.

Presentation of Honorary Life Membership to M. J. Gregory

By Lee C. Wilson, Past President, A.F.A.

The award of Honorary Life Membership to M. J. Gregory I am sure is a very popular one. Through his apprentice courses at Brown and Sharpe Company, he became interested in boys and in their development for the Foundry Industry and throughout his business career, in his quiet way, he has been instrumental in developing many valuable men for the Industry, and it is fitting that recognition of the value of such accomplishments be made.

Greg has brought his foundry to our conventions in his exhibits of molding and core work, which have been very educational to all those viewing these exhibits, and he has spent a great deal of time and energy in working up and demonstrating methods which he has developed.

M. J. Gregory is well known for his work as Factory Manager of the Foundry Division, Caterpillar Tractor Company, Peoria, Illinois. A member of A.F.A. for many years and a past director.

Mr. Gregory began his industry career as an apprentice at Brown and Sharpe Manufacturing Company, Providence, R. I. He also studied at Brown University and at the Massachusetts Institute of Technology, where he was a student of Metallography under the direction of the late Dr. Albert Saveur. Several important operating papers on foundry techniques were prepared by him for presentation at various technical meetings. Under his direction a "model" foundry staffed almost exclusively by women was set up at Caterpillar for the production of aluminum airplane cylinder heads.

Mr. Gregory is now retired and is a very busy man doing things that he has always wanted to do but because of his work in the foundry industry he had been unable even to approach them.

It is therefore my great pleasure to present to you, M. J. Gregory, the Honorary Life Membership in the American Foundrymen's Association, as directed by the Board of Awards.

PRESENTATION OF OTHER AWARDS

HONORARY LIFE MEMBERSHIP in the A.F.A. was presented, in absentia, to Rear Admiral A. H. Van Keuren, U.S.N., Director of the Naval Research Laboratory, Washington, D. C., *"in recognition of his efforts in behalf of the Foundry Industry."* Presentation by L. C. Wilson as Chairman, Board of Awards. HONORARY LIFE MEMBERSHIP was presented also to retiring President Ralph Teetor. Chairman Wilson paid tribute to the quality of leadership A.F.A. has had under the guidance of President Teetor, in laying the foundation for greater service to the entire industry.

Report on Election of Officers and Directors

Presented Before the Annual Business Meeting, Chicago, July 18, 1945

Members of the American Foundrymen's Association:

It is my duty and privilege, as well as pleasure, to report to you in accordance with the By-Laws, Articles X and XI, that the duly appointed Nominating Committee has presented to your Secretary their selection of nominees for officers and directors for election. This report was in accordance with our By-Laws published to our members through the pages of the AMERICAN FOUNDRYMAN.

Further, in accordance with the By-Laws, as no additional nominations have been presented from the membership, I am authorized to report to you the duly elected officers and directors as follows:

President to serve for one year:

Fred J. Walls, International Nickel Company, Detroit, Mich.

Vice-President to serve for one year:

Sheldon V. Wood, Minneapolis Electric Steel Casting Co., Minneapolis, Minn.

Directors to serve for one year:

R. J. Teetor, Cadillac Malleable Iron Co., Cadillac, Mich., as retiring President.

Director to serve for one year:

George K. Dreher, Ampco Metal, Inc., Milwaukee, Wis.
E. W. Horlebein, Gibson & Kirk Co., Baltimore, Md.
H. H. Judson, Goulds Pumps, Inc., Seneca Falls, N. Y.
James H. Smith, General Motors Corp., Detroit, Mich.
F. M. Wittlinger, Texas Electric Steel Casting Co., Houston, Texas.

Accordingly, I offer the motion, in accordance with the provisions of the By-Laws, Article XI, Section 1, "That the Secretary be instructed to cast the unanimous ballot of all members for election of candidates named by the Nominating Committee and as published to the members."

I feel that we as members of the Association owe a vote of thanks to the Nominating Committee for their work and selection. These members of the committee were:

Chairman D. P. Forbes—Gunite Foundries Inc., Rockford, Ill.
L. C. Wilson—1220 Parkside Drive, South, Reading, Pa.
R. K. Glass—Republic Steel Corp., Buffalo, N. Y.
Martin J. Lefler—Strom Brass Foundry, Elkhart, Ind.
W. E. Mahin—Armour Research Foundation, Chicago, Ill.
Henry McFarlin—The Lunkenheimer Co., Cincinnati, Ohio.
Charles Morrison—Saginaw Malleable Div., General Motors Corp., Saginaw, Mich.
John W. Porter—American Steel Foundries, East Chicago, Ind.
E. P. Trout—Lufkin Foundry & Machine Co., Lufkin, Texas.

Respectfully submitted,
R. E. KENNEDY,
Secretary.

Report of the National Judges A.F.A. 1945 Apprentice Molding and Patternmaking Contest

On Saturday, July 14, the judges of the National Apprentice Molding and Patternmaking Contest met and went over the entries which had been submitted for this competition. Following the procedure as laid out by the National Apprentice Contest Committee, the judges graded each entry, and the following are their selections as first, second and third winners in each of the classes:

Non-Ferrous Molding

First Prize—John Hronek, Wisconsin Aluminum Foundry, Manitowoc, Wis. Rating—77.

Second Prize—Frank Spano, Allis Chalmers Mfg. Co., Milwaukee, Wis. Rating—69.

Third Prize—John Chrnelich, Allis Chalmers Mfg. Co., Milwaukee, Wis. Rating—66.

Gray Iron Molding

First Prize—E. Doucet, Canadian National Railways, Montreal, Quebec, Canada. Rating—93.

Second Prize—Steve Grabowski. Rating—78.

Third Prize—H. Lalonde, Montreal Foundry, Montreal, Quebec, Canada. Rating—77.

Steel Molding

First Prize—Frederick C. Krueger, Birdsboro Steel Foundry and Machine Co., Birdsboro, Pa. Rating—89.15.

Second Prize—P. Crevier, Canadian Car & Foundry, Montreal, Quebec, Canada. Rating—81.5.

Patternmaking

First Prize—Anthony Taddeo, Birdsboro Steel Foundry and Machine Co., Birdsboro, Pa. Rating—98.

Second Prize—Robert Cech. Rating—92.25.

Third Prize—D. MacKenzie, Canadian National Railways, Quebec, Canada. Rating—88.25.

We are very pleased to note that a newcomer chapter to the contest was able to take three places, and our congratulations go to the Eastern Canada and Newfoundland Chapter.

Further, we wish to express our appreciation for the splendid cooperation of those men who were willing to give their time as judges. They were as follows:

Patternmaking

R. W. Schroeder, Washburne Trade School, Chicago.
Martin Rintz, Continental Foundry & Machine Co., East Chicago, Ind.
H. K. Swanson, Swanson Pattern & Model Works, Chicago.
Frank Mueller, Fdry. Supt., American Steel Foundries, Indiana Harbor Works.

Steel Molding

Martin Rintz, Continental Foundry & Machine Co., East Chicago, Ind.
Frank Mueller, Fdry. Supt., American Steel Foundries, Indiana Harbor Works.

Gray Iron Molding

Roy W. Schroeder, Washburn Trade School, Chicago.
C. G. Mate, Greenlee Foundry Co., Chicago.
F. H. Peterson, Fdry. Instructor, Northwestern Institute of Technology.

Non-Ferrous Molding

R. W. Schroeder, Washburne Trade School, Chicago.
John M. Sheridan, General Foreman, Brass Foundry, Crane Co., Chicago.

We feel very gratified that our Apprentice Committee under the chairmanship of Carl W. Wade of the Caterpillar Tractor Company, Peoria, were able to conduct the contest this year under conditions which were quite difficult because of the War, and which have made indentured apprentice training almost non-existent. We are most happy that this contest, started in 1924, has been carried through, and we are looking forward to more and more chapters fostering contests for future years.

Respectfully submitted,
R. E. KENNEDY,
Secretary.

Report of the A.F.A. Secretary
To 1944-45 Board of Directors at the Annual Board Meeting, July 18, 1945

IN REPORTING as your Secretary, this year we have to acknowledge that the year has been unusual inasmuch as wartime conditions necessitated our complying with the O.D.T. regulations, which led to the cancellation of our plans for holding our scheduled 4th Foundry War Production Congress at Detroit in May. This O.D.T. order caused concern and required considerable thought and immediate action in making plans for an alternate program, which resulted in what is called an all-year-round convention, carrying in the AMERICAN FOUNDRYMAN the papers and committee reports planned for the convention. The authors and committees have responded in a very gratifying manner, and we agree that the results are going to be satisfactory to all our members. In addition, the authors of papers have been contacted and many are willing to present their papers before Chapter meetings. These papers, after appearing in the AMERICAN FOUNDRYMAN, will later be rearranged and reprinted as in Volume 53 of our Transactions for the proceedings of 1945.

Membership

Due to the splendid work of our Membership Committee, under the chairmanship of Vice-President Fred J. Walls, consisting of all the Chapter membership committee chairmen, the Association started the year with 6,620 members as of June 30, 1944, and we have finished the year as of July 1, 1945, with 7,815 members, a record increase of 1,195, finishing the year with another all-time high total. A summary of the membership will be presented later and published in the Transactions. We like to feel that the membership record is a tribute to the real fundamental work done by the Association over the years since its organization. We are all so proud of the policy of the Membership Committee, which is "no high pressure, and any new member must want affiliation for the good it will do him and the good he can do for the A.F.A. before joining."

Further, in comparing records of similar organizations of professional and technical societies, we believe that our record of membership increase has been proportionately greater than any other technical society, for since 1934, our post-depression low of 1,250 members, we have had, year after year, a straight-line increase. In 1938 we reached an all-time high record of 2,477, and since 1938 each year has set a new all-time high record. It would take a wizard to estimate the potential membership if the A.F.A. continues to serve the foundry industry as in the past. It is interesting to note that this membership increase began in 1934, coinciding with the starting of our first Chapter.

Chapters

The year 1934 saw the initiation of what we now know was one of the most important actions or movements in our Association history. That year the Board of Directors approved the formation of Chapters to hold monthly meetings, bringing together members of various districts for discussing foundry papers and foundry problems. Following the formation of the first Chapter, which was the Chicago Chapter, the idea was immediately popular and year by year additional Chapters have been formed until now there are 31, ranging in location from Montreal and Toronto, Canada, on the north, to Houston, Texas, on the south, and from 3 West Coast Chapters to 3 on the East Coast, with the bulk being largely centered in the heavy foundry states of the central Great Lakes area.

This past year four new Chapters were formed, these being Central Ohio, with headquarters in Columbus, Ohio; the Oregon Chapter, with headquarters in Portland; Saginaw Valley, with headquarters in Saginaw, Mich., and Northwestern Pennsylvania Chapter, with headquarters in Erie, Pa. Other districts are showing interest in the possibility of Chapter organization, and it is expected that several new Chapters will be organized in 1945-46. In this connection, it is interesting to note that a member in Mexico City has hopes of later organizing a Chapter there, and at the present time is trying to build up membership to this end. It has been the policy of A.F.A. to encourage local groups to form Chapters, as we know an ideal condition would exist if every member could attend a Chapter meeting quite regularly, although this ideal will not be possible to reach because of the scattered geographical location of some of the members. We now have 93.4 per cent of our members affiliated with Chapters.

After several years of holding Chapter delegate meetings at the time of the annual conventions, last year the Board of Directors thought that the Chapter chairmen should be brought together in a special meeting to review and discuss problems of Chapter operation. At this meeting held a year ago during August all the Chapters except one were represented. Those attending felt that the meetings were worthwhile and that it should be an annual affair and should cover two days instead of the original one, so as to give more time to full discussion of important subjects. Accordingly, this year a meeting has been held here in Chicago on July 17th and 18th, using the occasion to stage the annual A.F.A. Business Meeting.

The Board's Chapter Contact Committee under the chairmanship of I. R. Wagner has this past year provided a schedule for official visits to each chapter by the President, Vice President, and members of the Chicago Staff. This policy of annual official visits is recommended, as it is believed that by this meeting all Chapters can be better directed and more satisfactory maintenance of Chapter relations with the national office. It is realized that next year this official visitation may have to be curtailed due to wartime travelling conditions.

Finance

The Finance Committee of the Board annually consists of the chairman, who is the junior past president, the President and Vice President. Each year this committee with the staff develops a budget of estimated income and expenses. This past year the budget estimate has been exceeded in the total of all the income items and the total of the expense items was less than estimated. The Treasurer's report giving financial statement will be presented in detail by Treasurer Ed Hoyt and published in the Transactions for the information of the members.

By-Laws

This has been the first year of operation under the By-Laws effective July 1, 1944. The Board acting under these provisions has seen fit to increase the company and sustaining membership dues, raising the company membership dues from $25.00 to $50.00 and the sustaining membership dues from $50.00 to $100.00 minimum. No change was made in the dues of the other classes of members. It has been gratifying to note the response of company and sustaining members to this increase, and it is believed that the increase will show a substantial return to the Association over the old rate, giving the Association greater opportunity to carry out more fully the work which has been planned.

Technical Committees

Our Special Interest Technical Committees were this year set up and organized as usual. They have continued to function in a very splendid manner, though the cancellation of the convention prevented them from holding their usual meetings at the annual conference. Special credit must be given to these committee members for their work under these circumstances. In addition, some have done outstanding work

and we wish to review here briefly some of these activities.

(a) *Ordnance Committee*

Of most significant interest was the request from the office of Major General Barnes, Chief of the Research and Development Section of the United States Army Ordnance Department. This request invited the A.F.A. to organize a committee, representative of our divisions, which would work with the Ordnance Department on a long-time program of solving foundry problems connected with the Ordnance development. This request was immediately referred to our Board and after conference with the Ordnance Department, a committee was formed under the chairmanship of Vice-President Fred Walls. It is expected that this committee will be increasingly important over the years, and the Association is very pleased to cooperate in this undertaking.

(b) *Casting Inspection Committee*

The youngest of our committees organized before the 1944 Convention called the Inspection of Castings Committee has this year held monthly meetings in our office, with its objective being the preparation of a Casting Inspection Manual, and as a side issue is planning to interest management in the need for giving greater consideration to casting inspection from the standpoint of the user. Some sections of this manual have been published in the AMERICAN FOUNDRYMAN. Others will follow, with the complete manual being issued later as a special reprint. The meetings of this committee will be resumed again next September. On completion of its present objectives, the addition of others will be determined.

(c) *Malleable Division*

The Malleable Division through its program committee has completed four annual symposia on Malleable Foundry Practice. These symposia, instituted several years ago, were planned with the end in view of producing material for an extensive book on modern malleable foundry practice. To date the four symposia completed cover the following:

Graphitization of White Cast Iron
Malleable Melting Practice
Gating and Heading Malleable Castings
Malleable Foundry Sand Control

One or two other symposia covering such subjects as Finishing and Coremaking, plus a few special papers, will complete the project as originally planned, and it is realized that this book will be of great value to the industry. Further, plans are being considered for the periodic revision of keeping material up to date. This activity is a logical project for submission to the Technical Development Program under its broad publication and periodic revision program.

(d) *Apprentice Training*

While foundry apprenticeship has been practically out of the picture due to the demands of the War, our Apprentice Training Committee (first formed in 1926) has kept its flag flying this past year, for it has completed its annual Apprentice Molding and Pattermaking Contest. While the competition was limited due to the available indentured apprentices, it is interesting to note that a new Chapter is entered in this year's competition, with these new entries coming in from the Eastern Canada and Newfoundland Chapter.

These annual contests, started in 1924 at Milwaukee, have done much to stimulate interest on the part of companies and the Chapters in foundry apprentice work. Certain Chapters have been our leaders in this work, with Wisconsin the pioneer, and Northeastern Ohio, Quad City, Chicago, and St. Louis all doing good work. The individual companies that have been constant competitors are Brown & Sharpe Mfg. Co., Providence, R. I., Birdsboro Foundry & Machine Co., Birdsboro, Pa., and the Caterpillar Tractor Co., Peoria, Ill. Our appreciation goes to J. G. Goldie of Cleveland Trade School, Past Chairman of the Apprentice Training Committee, and Carl Wade of Caterpillar Tractor Co., Peoria, Present Chairman.

It is the hope of this committee that as conditions caused by the War improve, more and more of our Chapters will sponsor real training programs and contact local schools to interest youngsters in the foundry by organized plant visitations and sponsoring talks before school groups. We believe that this activity is one which the Chapters, because they are close to local conditions, can be of greatest assistance in promoting organized training work to bring youngsters in the industry.

(e) *Foundry Cost Committee*

Our Foundry Cost Committee, under the chairmanship of R. L. Lee of Grede Foundries, Milwaukee, with official representation from the foundry trade associations and societies, has completed and published its study of classification of foundry cost factors and a revision of Recommendations to Buyers of Castings. It is now turning its attention to the preparation of a publication of recommendations on the most fundamental cost systems for the use of the smaller foundry. It is believed that such a publication will fill a most worthwhile and needed work and be of great value to the industry.

(f) *Job Evaluation and Time Study Committee*

This committee has been functioning under the chairmanship of Robert Fisher of The Falk Corporation, Milwaukee. Its activity has produced some good papers, which are being published in the AMERICAN FOUNDRYMAN. It has as a major future project the compilation of a booklet on the scope and place of time and method study in the smaller foundries. This past year A.F.A. Director J. H. Smith, Manager of Saginaw Malleable Div., General Motors Corp., Saginaw, Mich., has presented before Chapters a remarkable demonstration of the application of time and method study to the foundry.

(g) *Cooperation with Engineering Schools Committee*

The Committee on Cooperation with Engineering Schools, under the chairmanship of F. G. Sefing of International Nickel Company, New York, has had to spend most of its time, due to the wartime conditions, in planning cooperation with the engineering schools. The Chairman is now organizing the committee for intensive work as soon as conditions improve, and is planning on promoting closer cooperation between the Chapters and the local schools, as this is a field where the Chapters can be of the greatest aid to the national office. The plan calls for sponsoring regional meetings, with the Chapters cooperating with the engineering schools, having three objects in mind:

(1) Increasing knowledge of the engineering staff in castings;

(2) Promoting acquaintanceship of foundrymen with the engineering school work;

(3) Educating students on the possibility of the foundry as their vocation.

The committee now has a very strong organization for this future work.

Gray Iron Division

The Gray Iron Division has started a new committee, that on Specifications under the chairmanship of T. E. Barlow. This committee is not to propose specifications or in any way conflict with our work with the A.S.T.M., which we recognize as a specification making body, but is to study all Society standards and company specifications, suggesting ways of bringing these in harmony with the best practices.

(a) *Study of Causes and Remedies for Casting Defects*

This committee for several years under the chairmanship of W. A. Hambley of Allis-Chalmers Mfg. Co., Milwaukee, has continued its monthly meetings in the A.F.A. office. It has nearly completed its intensive study of causes and defects and has classified these, and may shortly be publishing its study with illustrations as a complete work.

(b) *Cupola Research*

A major activity of the Division for some 5 years has been that on cupola research. This work is being carried on under the supervision of the Technical Development Program and will be covered in the report by the Director of the T.D.P.

(c) *Engineering Uses of Cast Iron*

This committee under the chairmanship of R. G. McElwee

of Vanadium Corp. of America, Detroit, this past year has continued its efforts to complete a series of papers on engineering uses of cast iron. The report on investigation of cast iron for high temperature uses has been published, and other series are ready for publication. It is expected that when the complete report is published as a special bulletin, it will be a most valuable addition to our literature for showing the place of cast iron in engineering construction.

(d) *Inoculation and Chill Tests*

These two committees are under the chairmanship of T. E. Barlow and they will have published in reports and papers the outline of their work and study.

(e) *Heat Treating Terms*

The Joint Committee of S.A.E., A.S.T.M., A.S.M., A.F.A., on which the representatives of the A.F.A. are H. Bornstein and J. S. Vanick, has been active and has just completed a revision of its Glossary on Heat Treating Terms, and has submitted these for review and approval to the sponsoring groups for final printing.

Steel Division

The Steel Division through its Program Committee has submitted an extensive series of papers on Non-Destructive Testing, a subject of foremost importance to the steel casting producers.

Aluminum & Magnesium Division

While one of our youngest divisions, this division has been most active this past year and has secured a splendid series of papers on magnesium casting practices. Recently, R. E. Ward of Eclipse Pioneer Div., Bendix Aviation Corp., Bendix, N. J., has been elected Chairman of the Division, and it is expected that an unusually active year will result. Recently, cooperating with this Division are two trade associations, with official representation on our Executive Committee of the Division, these being the Aluminum Research Institute and the Magnesium Association.

Patternmaking Division

This Division has been especially active in stimulating Chapters in organizing pattern discusson groups. Frank Cech, as Chairman, reports that pattern groups have been started in the Wisconsin, Chicago, Texas, and Northeastern Ohio Chapters. It is hoped that all Chapters before long will have such groups, giving greater emphasis to the cooperation between foundry and pattern shops.

Brass and Bronze Division

Under the chairmanship of B. A. Miller, the Brass and Bronze Division can take great pride in the completion and publication of the first edition of the book entitled "Recommended Practices for the Sand Casting of Non-Ferrous Alloys," a project initiated some 15 years ago. The Division plans a complete program of sessions for the next annual meeting.

Publications

(a) *Transactions*

One of the regular publications of the Association has this year resulted in publication of Transactions Volume 52, the proceedings of the 1944 Buffalo Congress. It comprises a volume of 1,493 pages, the greatest number of pages of any previous Transactions, with Volume 51 containing 1,075 pages, the greatest number up to that time.

(b) AMERICAN FOUNDRYMAN

With the cancellation of the 1945 Congress, the Board approved the publication in the AMERICAN FOUNDRYMAN of all papers which would have been presented to the Congress, sending copies of the AMERICAN FOUNDRYMAN to members, the papers later being incorporated with any written discussion in Transactions, Volume 53. In addition, beginning with the May issue and continuing through December, the Board approved the policy of carrying paid advertisements. This plan has worked well with the distinct approval of the membership.

At this time, we wish to acknowledge the excellent work of C. R. McNeill for his editorial work on the Transactions, and the work of Jerry Buhler, who has returned to us after service with the Navy, as Assistant Editor of the AMERICAN FOUNDRYMAN, while Terese Koeller has done an outstanding job as Assistant Advertising Manager for the AMERICAN FOUNDRYMAN.

This past year the Association has been extremely fortunate in having one of its members, B. L. Simpson, President of National Engineering Co., do an outstanding piece of research on the history and development of metal castings industry. Mr. Simpson has worked most effectively in getting together most interesting data and information on the history of the castings industry, and A.F.A. will be the publisher, carrying the book by sections month by month in the AMERICAN FOUNDRYMAN, later reprinting the material in a book which we know will be of outstanding interest to every man connected with the foundry industry.

We cannot speak too highly of the most exhaustive study made by Mr. Simpson, and we find that his manuscript which contains some 140 pages plus some 200 illustrations will be, I am sure, of the greatest interest to our industry and the lay reader. We have every confidence that it will be a most valuable asset to our published literature, giving the foundrymen the inspiration and pride in its industry for its place in industrial development.

Technical Development Program

A year ago the Board authorized the separation of our technical and publishing activities into two groups. One is called our regular activities, and all special publications and research volumes are combined under what we call a Technical Development Program. This move was made to broaden and strengthen the work the A.F.A. has been carrying on since it was organized in 1896. The Technical Development Program has been placed under the direction of Norm Hindle, for years Assistant to the Secretary, working with the Advisory Committee under the chairmanship of S. V. Wood, with representation from management, technical, and operating groups of various divisions. For financing the work of the Technical Development Program, contributions have been made by the members of the Association and by the A.F.A. We have every confidence that when the first annual report of T.D.P. is published, everyone will agree that this work meets with universal approval and commendation.

While no one can predict at this time what plans will materialize for the coming year, we have every hope that it will be possible to celebrate our 50th Anniversary in 1946 with an outstanding major exhibit and combine this with an International Foundry Congress.

We wish to express our utmost appreciation for the helpful cooperation and aid of President Teetor and Vice President Walls and all our directors, for they really have been a working group, and further, we wish to express our appreciation for the most helpful cooperation of our staff members, Ed Hoyt as Treasurer, Jennie Reininga as Assistant Treasurer, W. W. Maloney as Business Manager, Norman Hindle as Director of the Technical Development program. I can truthfully say that I feel our staff has been working well together under strenuous conditions, due to the problems imposed by the conditions necessitated by the cancellation of the 1945 Convention.

Respectfully submitted,

R. E. KENNEDY,
Secretary.

Membership Report

(Three-year comparison, as of June 30, 1945, 1944 and 1943)

	June 30, 1945	*June 30, 1944*	*June 30, 1943*
Book Membership	7,815	6,620	5,665
Sustaining	182	169	113
Company	1,651	1,471	1,341
All Other, Except Foreign	6,373	4,871	4,091
Foreign	217	163	120
New Members	1,803	1,510	1,172
Net Gain	1,195	955	618
Resignations	235	215	150
Delinquents Dropped	356	316	384
Removed by Death	17	24	20
In Chapters	7,110	5,904	5,003

Distribution of Membership by Chapters

On June 30, 1945

Chapters	*Sustaining*	*Company*	*Personal*	*Affiliate*	*Associate*	*Apprentice*	*Student*	*Honorary and Life*	*Total*
Birmingham	3	45	31	150	4	0	0	2	235
Canton	1	27	9	63	0	0	0	0	100
Central Indiana	5	34	21	114	2	0	0	0	176
Central New York	1	32	27	74	5	0	0	1	140
Central Ohio	2	34	16	128	5	0	1	1	187
Chesapeake	7	33	22	83	57	1	0	2	205
Chicago	29	111	84	461	21	5	1	7	719
Cincinnati	8	54	27	122	4	0	0	2	217
Detroit	13	68	54	233	17	0	4	7	396
E. Canada and Newfoundland	4	70	42	150	11	0	0	0	277
Metropolitan	13	63	49	201	15	0	0	2	343
Michiana	3	30	22	113	1	0	0	0	169
Northeastern Ohio	23	99	63	249	10	0	1	7	452
Northern California	7	28	67	164	11	0	0	0	277
No. Illinois-So. Wisconsin	5	18	5	36	0	0	0	1	65
Northwestern Pennsylvania	0	15	4	54	0	0	0	0	73
Ontario	3	106	66	68	4	0	0	1	248
Oregon	3	11	8	41	1	0	0	0	64
Philadelphia	19	63	46	133	12	0	1	5	279
Quad-City	6	50	28	143	5	0	1	3	236
Rochester	2	15	10	71	4	0	0	0	102
St. Louis	3	57	35	129	4	0	0	0	228
Saginaw Valley	6	10	0	187	2	0	0	1	206
Southern California	7	81	85	146	12	0	0	0	331
Texas	6	32	23	59	2	0	0	1	123
Toledo	0	23	14	53	1	0	0	1	92
Twin City	3	42	22	92	10	0	2	0	171
Western Michigan	5	34	10	156	0	1	0	1	207
Western New York	4	39	40	153	3	0	0	2	241
Wisconsin	22	108	41	364	12	2	0	2	551
Total in Chapters	213	1432	971	4190	235	9	11	49	7110
Outside of Chapter	26	139	91	229	6	1	2	6	500
	239	1571	1062	4419	241	10	13	55	7610
Foreign	.....	.....	.....	.....	.....	....	....	....	205
TOTAL MEMBERSHIP (June 30, 1945)									7815

Report on Finances

THE financial considerations of your Association during the fiscal year ended June 30, 1945, should properly be considered under two separate headings: first, the General Activities of the Association, and second, the Technical Development Program Activities. This is because the Technical Development Program was set up to be operated with funds kept entirely separate from those used to finance other activities, in keeping with obligations to those who contributed to the Program so generously.

The accounts of the Association were audited on June 30, 1945, in accordance with the By-laws, by Robert T. Pritchard, Auditor, of Chicago, and the accompanying condensed balance sheet indicates the financial status of A.F.A. on that date. In addition to liquid funds for current operations, the Association maintains other funds as follows:

(a) The Award Funds, administered by the Board of Awards, only the interest on the principal of these funds being utilized for purposes of annual or periodical awards for outstanding contributions to the industry;

(b) The General Reserve Fund, added to periodically and held intact for future contingencies;

(c) The Cupola Research Fund, made up of contributions to the Cupola Research Project, administered by the Association but utilized only for actual Cupola Research work;

(d) The Technical Development Program Fund, composed of contributions to the Program, plus an original $25,000 allocated from the General Funds of A.F.A. for initiation of this important activity.

Both the General activities of the Association and Technical Development Program activities are governed by annual budgets set up by the Finance Committee and approved by the Board of Directors. As a non-profit corporation, any surplus of A.F.A. funds at the end of any one fiscal year are allocated to one or more of the several maintained funds or appropriated for operations during the following year.

Consideration of the combined income and expense of General activities and Technical Development Program activities, reveals a total income of $207,811.56—including Dues income of $103,281.22; Subscription and Publication sales, $43,709.01; Advertising in the pre-Convention issue of AMERICAN FOUNDRYMAN, $15,026.34; Appropriation from 1943-44 income, $20,000; and $25,000 appropriated from the General funds for the Technical Development Program. It should be pointed out that, since exhibits of foundry equipment and supplies are staged in conjunction with Annual Conventions of A.F.A. in even-numbered years, some part of the income received during an exhibit year may properly be appropriated for operations during the following non-exhibit year.

Combined expenses during the fiscal year 1944-45 totaled $187,763.85—major items of expense, over and above Staff Salaries (a major item with any service organization such as A.F.A.), included $63,712.09 for Production of Special Publications and Books; $19,519.63 in Refunds to Chapters through prorating dues income; and $11,535.24 for expense in connection with Committee, Chapter and Regional Meetings.

Because of expanding activities of the Association, brought about through constantly increasing membership and growing demands for additional activities, a study now is being made of our accounting methods with a view toward some amplification of data. Establishment of the Technical Development Program has already indicated the unlimited possibilities for performing greater service to the industry in accordance with established business practices. It is hoped that the current accounting analysis will facilitate the financial work involved in performing the growing service demanded by our members.

In view of the past year's experience in financing the general activities of A.F.A. and the Technical Development Program under separate budgets and accounts, it is recommended that the Finance Committee give serious consideration to a combined budget of income and expense for future years but without altering in any way our obligation to maintain Technical Development Program funds intact for such work as may be allocated to the Program.

Condensed Balance Sheet

As of June 30, 1945

ASSETS

Cash	$ 86,920.86
Securities	131,993.90
Accounts Receivable	2,404.59
Inventories	21,364.52
Prepaid Expenses	206.73
Furniture and Fixtures	2,017.93
	$244,908.53

LIABILITIES

Accounts Payable	$ 374.40
Reserves	71,289.59
Unexpended Special Funds	120,355.77
Deferred Income	8,893.70
Surplus	43,995.07
	$244,908.53

President's Recommendations to the Board of Directors at the Annual Board Meeting, July 18, 1945

DURING my term of office I have often referred to the reports of former presidents to the Board of Directors upon their retirement from office. I find especially the report of past president Duncan Forbes of great interest. The following paragraphs which I submit cover some subjects on which I have formed opinions during the past year, and I hope that these thoughts may be of some value to the Association. They are, of course, not original in all instances and are far from complete.

I am aware that some of my ideas are not shared generally, and certainly this report will not cover many important phases of the administration of A.F.A., but will touch only here and there upon matters which I feel I should put in writing for record. Many of my suggestions are identical with those offered by my predecessors.

Uppermost, at the moment, is the need for substantial strengthening of the National Office Staff. Upon the assumption that the recommendations of the Executive Committee as of April 26-27, 1945, will be adopted by the Board, the new administration is faced with a set of circumstances at the outset that are out of the ordinary, and such that will require more than the usual amount of attention from the new officers and the Board than has generally been necessary in the past.

Without a single exception, we have in our office in Chicago, in my opinion, personnel possessing professional qualifications or skills of a high order and of a character that is needed and required to carry on the functions of the office. There has existed, however, a need for more complete coordination of the functions of those in the office, and I have no doubt this will continue to some extent during the remaining period of the war and until much needed increases in personnel may be properly made.

Executive Committee Meetings

However, in view of that circumstance, it becomes incumbent upon the new officers and Board to work more closely with the permanent staff than ever before and to give them more assistance and directive instruction than would normally be considered warranted. To this end I would recommend that in addition to customary Board meetings in January and July and interim Executive Committee Meetings in October and April, Executive Committee meetings be held not less often than bi-monthly.

Plan of Organization

With the increasing membership of A.F.A., and the ambitious program embarked upon by the T.D.P., it has been obvious that we are under-staffed to properly expand our functions as planned. It will naturally be the objective of the incoming administration to correct this situation as quickly as feasible.

To this end, however, I recommend that a special committee of the Board or of the Executive Committee be charged with an early detailed study of the plan of organization for the National Office, with a view to correcting any deficiencies which exist in view of the rapidly changing conditions which continue to confront the administrative office. Functional schedules have been prepared in the past, but I do not believe they have been very closely followed and, of course, an organization chart in an institution like ours naturally must change frequently. But I do believe that a complete reconsideration of the functions of our staff people would be helpful to them in doing efficient planning for the coming months.

Staff Coordination

In regard to the Technical Development Program which, I believe, now becomes the principal business of the A.F.A., I feel it is important that the Director of this Program be convinced that the functions of T.D.P. constitute the principal objectives of A.F.A., and that complete coordination must be maintained between the activities of T.D.P. and the executive head and staff of the National Office.

With this in mind I recommend that a daily conference be held at the National Office presided over by the Secretary, and that in attendance there should be those charged with advertising, publications, editorials, general office procedure, T.D.P. and any other important functions that may exist. I believe such meetings should be limited to ten or fifteen minutes for the purpose of bringing out immediately any questions that may involve any of the several departments and with the expectation that such short conferences would help in disposing of matters of general interest with expedition and efficiency.

I recommend that a weekly conference of the same character be held for a longer period, perhaps one or two hours as may be necessary under the circumstances. Such conferences have been found by industry to be invaluable in eliminating duplication of effort and misunderstanding of minor details, and I believe such conferences, if limited in time and if properly directed, can be very useful to our National Office Staff.

Retirement Plans

Events of the past year have convinced me that there is a need in our Association for some definite retirement plan for staff members to look forward to and to be guaranteed by long-range financing. It is but natural for all employees —for professional assistants or executives who are desired as permanent members of the A.F.A. Staff—to give consideration to what the long-term future holds for them as the years go by, and I believe it would be wise for our Association to formulate a plan which should be financed by the Association.

Personnel Employment

I believe it might be wise for the Board to place a salary limit on persons who may be employed by the Secretary of the Association without securing the approval of the Finance Committee. I suggest this for the comfort and protection of the Secretary himself and in order that his actions in such matters may at all times be entirely free from possible criticism. The salary limit might be $3,000 or $4,000 or higher, depending, of course, upon changing circumstances. However, in any event, it should be made plain that the employment of all personnel, with the exception of those elected by the Board, is solely a responsibility of the Secretary.

Business Methods

I recommend that a detailed study be made of the business methods employed in the National Office, with a view to more efficient servicing of our greatly expanded membership. I believe this has already been considered, but I feel that every effort should be made to follow through without delay.

T.D.P. Solicitation

In the matter of solicitations for T.D.P. financing, there have been some critical comments from some of those solicited. This is to be expected, as no worthwhile accomplishment is ever concluded without opposition. I believe, however, we have now reached the end of any solicitation campaigning by letter to the general membership. There remain many members, who if we could reach the right people, might become generous subscribers.

Trade Association Relations

I wish to revert to the recommendation made by Duncan Forbes to the effect that we should consider definite ways of attracting the executives of foundry trade associations and also, perhaps, F.E.M.A. and Supply Dealers' Association to more active participation in the affairs of A.F.A. I am thoroughly in agreement with this suggestion and am sorry that more progress toward it has not been made during my administration.

New Chapters

Our National Headquarters, and especially Bob Kennedy, have had a record year in Chapter expansion, for which they deserve congratulations. It is, however, probable that few logical locations remain for new Chapters according to our present standards. In my opinion we should give reconsideration frequently as a Board, to the conditions under which a Chapter may be admitted, taking into account location, potential membership, influence on neighboring Chapters in the matter of adversely affecting their membership, and, of course, probability of survival as a going institution.

I have in mind at the moment a situation in one area where a large and strong Chapter quite naturally desires to hold its membership to a certain maximum figure for very legitimate reasons of efficient administration. It is important that in such a situation we give consideration to groups who may be desirous of Chapter affiliation but because of distance or large membership in the nearest Chapters find it impracticable to affiliate themselves or to participate in Chapter activities. Possibly working out a branch group similar to one under the administration of the mother Chapter would be the answer, at least temporarily.

I do feel that Chapter influence is so great a constructive force in strengthening the A.F.A. in its general objectives that careful consideration should be given frequently to the possibility of new Chapters or separate groups affiliated with an existing Chapter in order that the advantages of Chapter membership may be as broadly distributed as possible. I feel too that in certain distant areas it may be desirable to change our ideas as to the minimum number of members that might be required for the formation of a Chapter.

Membership Work

Many opinions, recently, have been expressed as to possible losses of memberships in the Association with the end of the war and perhaps to some extent due to the increase in dues recently approved, and I grant that these circumstances will contribute toward reduction in membership in the Association. On the other hand, I am convinced that the increase in membership in the Association since the inception of our chapter organizations will continue if our chapter structure continues healthy and properly coordinated with the National Office and if we effectively carry out our functions, including T.D.P. development, and gradual improvement of THE AMERICAN FOUNDRYMAN as we have promised ourselves and our members.

I believe that if those things are done, nothing can stop the growth of the membership of A.F.A. to a substantially larger number than our present membership. I believe that a continuing, well considered campaign should be made for memberships from the many foundries, many of them small, who are not and perhaps never have been members. I believe there are ways to reach these people. Of course, not all of them, but many.

The objective, as I see it, from the purely business standpoint is not primarily for the benefit of their dues, but the prestige of a larger membership which would enhance the value of THE AMERICAN FOUNDRYMAN as an advertising medium, and more important than all other considerations, the acceptance of the services offered by A.F.A. by a larger number of foundries for the benefit of the foundry industry in general.

It is trite, of course, for me to repeat our well known objectives as an Association, but I believe that a thorough job of continuing effort will result in the acquisition of many more members. Don Reese recently said he couldn't understand why the A.F.A. didn't have 15,000 to 20,000 members, and I agree with him to the extent that I believe we should have that many within a few years' time by concentrating on the programs which have already been initiated and by proper campaigning for new members.

Use of T.D.P. Funds

I consider the financial outlook of the Association excellent. I wish, however, to record my thought that we should definitely make sure that money which we acquire through contributions to T.D.P. or otherwise is used for the purposes intended beyond any reasonable question.

I wish to thank the members of the Board and the Executive Committee who have given much valuable time to the Association work. I have enjoyed the experience of my association with you more than I can say and the year, which looked quite long a year ago, has really been very short from my standpoint.

Very sincerely yours,
RALPH J. TEETOR, *President,*
AMERICAN FOUNDRYMEN'S ASSOCIATION

Report of "American Foundryman" Policy Committee

Presented at Annual Meeting of Board of Directors
Chicago, July 11-12, 1944

THIS is a report of the AMERICAN FOUNDRYMAN Policy Committee for the Association year just ending. In making the report, the committee is cognizant of the fact that the manpower situation in the National Office is similar to that which exists throughout industry generally and consequently instead of criticising the staff for anything they may or may not have done, it would compliment Messrs. Hindle and Maloney for the excellent job which they, under the guidance of the National Oficers, have done under such trying circumstances in carrying on the publication of the magazine. The report, therefore, merely reviews the existing situation and offers some suggestions for the possible betterment of the paper, which the staff and the incoming administration may wish to consider.

The scope of the AMERICAN FOUNDRYMAN with its editorial technical news, chapter activities and abstracts sections, is considered adequate to meet the present needs of the Association's members. Later, a research section may become desirable.

The editorial page provides the medium through which the National officers and chairmen of the major committees may present their views in a direct and personal way to the membership at large.

Technical Section

The technical news section is the channel through which practical information may be passed on to the worker in the foundry. A large and increasing percentage of the membership now consists of hourly workers, foremen and others whose facility for securing information as to what others are doing is somewhat limited, and it is to this group that the technical news section probably has its greatest appeal. To maintain their interest, and at the same time render the greatest service, the articles published must be practical in nature and easily read.

Chapter Activities

The chapter activities section is intended to keep the members advised as to what the other chapters are doing. While the section is interesting as now edited, it is believed that the major emphasis should be placed on abstracting the technical talks given at the meetings rather than on recording the social activities. To facilitate the procurement of such news, each chapter should be requested to appoint a reporter to whom the editors may look for such information.

Technical Abstracts

The abstracts are unquestionably worthwhile and should be continued. Further, when the personnel is available, they might be augmented each month by a comprehensive, correlated abstract covering some phase of foundry activity such as precision castings, the substitution of plastics for metal castings, ladle inoculations, etc. Later, when the research activities are more effectively under way, the writing of such articles should be practical.

Advertising

Finally, the question of advertising—for the first five years of its existence the AMERICAN FOUNDRYMAN carried no advertising. The reasons given were: first, the foundry supply men, upon whom the magazine would have to depend for advertisements, were contributing substantially to the Association's activities through the exhibitions, and hence should not be asked for more; second, such a move would put the magazine in competition with existing trade journals which, editorially, had loyally supported the Association through the years, and, finally, there were not a sufficient number of suppliers to effectively draw upon.

The validity of these arguments, of course, has ceased to exist. The AMERICAN FOUNDRYMAN is probably the only publication which the average foundry worker receives directly through the mail and hence it is the one in which he has the most interest. The trade journals in many cases are not available and, in any event, he probably does not have an opportunity to take them home for study as he would his own paper. With our constantly increasing membership, many of whom are not reached in any other way, advertising in the AMERICAN FOUNDRYMAN represents an investment rather than a contribution.

In entering the field of advertising the American Foundrymen's Association is simply following the lead of the American Society for Metals and the American Society for Testing Materials. Both of the latter societies have profited by the activity and it is doubtful if either the *Iron Age* or *Steel*, for instance, has suffered through this competition. With the increasing use of heat treatment in the processing of both ferrous and non-ferrous castings and the more exacting customer specifications requiring more elaborate test facilities, the number of suppliers contacting the foundries have considerably broadened and hence the field upon which the AMERICAN FOUNDRYMAN may draw is now quite large.

Pre-Convention Issue

Two years ago Mr. Hoyt, realizing that the former arguments were more or less obsoleted, decided to accept advertisements in the pre-convention issue. This turned out to be a decided success. Entirely through the efforts of the National Office, some 162 pages of advertising were secured at a net income of $25,332.70. The cost of producing the issue was $12,525.82, leaving a surplus of $12,806.88, which was adequate to cover the cost of the publication for the remaining eleven months. The AMERICAN FOUNDRYMAN thus, for the year, ceased to be a financial liability.

The logical question then was, if so much money can be made on one issue, why not make more by carrying advertisements in all issues? The answer, of course, involves more than simple multiplication. The pre-convention issue has natural buildup which other issues lack. If advertising is to be effectively carried in all then all must be of similar quality and attractiveness. This involves additional personnel, part editorial and part soliciting and regulating advertising.

The policy committee asked the National Office to investigate the probable cost of carrying out such a program and the profits which might be realized therefrom. This they later agreed to do but at the same time they pointed out that the information would probably be of little immediate use since paper was not available for such an activity without either reducing the editorial matter, both of which would be undesirable. Because of the War Production Board's regulations, difficulty was experienced in obtaining enough paper for the advertising section of the pre-convention issue.

Appreciating both the impracticability of any immediate action in starting an advertising program and the shortage of manpower in the office, the committee withdrew its request and the analysis was not made. The Board, however, approved the carrying of advertisements in the pre-convention issue this year, as paper could be made available for a repeat activity, and again the results were highly satisfactory. Some 144 pages of advertising were secured with a net income of approximately $25,000 and at an overall cost of approximately $10,000.

It would again appear that the surplus will be sufficient to cover the publication for another year. The pre-convention issue should be continued but, in addition, the committee recommends that when paper and manpower appear available, full consideration be given to the question of expanding the advertising activities.

Committee Personnel

The present committee believes that the number of members of the Policy Committee should be increased to include possibly a half dozen representatives from the Association membership. These individuals, along with the three directors, would, as in the past, act as an advisory board to the editorial staff. The non-director members might hold office for a period of say two years with rotation so that two replacements would be appointed each year. It is believed that the enlargement of the personnel would provide a broader viewpoint editorially and would tend to develop closer contact with the various chapters.

Respectfully submitted,
R. J. ALLEN, *Chairman*
I. R. WAGNER
S. V. WOOD

1st Annual Chapter Chairman Conference

Palmer House, Chicago—August 26, 1944

PROGRAM

10:00 AM ASSEMBLY AND GET-ACQUAINTED.

10:30 AM MORNING PROGRAM.

Welcome to Chapter Chairmen.

History and Organization of A.F.A.
Outline of the origin, development and aims of A.F.A.

Chapter Contacts.
The function of the Chapter Contact Committee and the value of chapter thinking in the framing of Association policies.

Technical Committee Work.
How the more than 100 technical committees and subcommittees of A.F.A. operate. Recent and forthcoming A.F.A. literature.

Chapter Program Building.
Building a program to *serve the membership.* The Program Chairman—a thankless job? How the National Office may be of help—the "Speakers' Bureau."

Regional Meetings.
Organizing the successful Regional meeting. Prospects for future meetings. Inter-chapter cooperation.

Educational Courses.
When is a chapter-sponsored educational course a sound undertaking? What is its purpose?—its value?—the possibility for support? How is one financed?

Apprentice and Student Activities.
What A.F.A. has done to encourage foundry apprentice training and student interest. Local and National apprentice contests. The future of apprentice training in foundries. The problem of returned veterans.

1:00 PM LUNCHEON.

2:30 PM AFTERNOON PROGRAM.

Cooperation with Engineering Schools and Colleges.
Raising the standard of foundry personnel. Interesting the engineering school instructor.

Management Committee.
What chapters can do to obtain the active backing of Management.

Youth Encouragement Committee.
Methods of interesting youth in foundry work as a career. Overcoming prejudice of school teachers.

Review of Chapter Manual.
Bringing the present manual up-to-date.

Chapter Membership Work.
Present trends in membership. Desirable ratios of Company to Personal members. Guidance and direction of Membership Committees by Chapter Chairmen.

Technical Development Program.
Its purpose, organization and work—its present scope and future possibilities—its importance to A.F.A. members and the industry in general.

"The Shakeout."
How can the National Office be of greater service to your Chapter?

4:30 PM ADJOURNMENT OF PROGRAM.

6:00 PM DINNER.

Speaker: Dr. Ralph Lee, Personnel, General Motors Corp., Detroit.

Subject: "Building Plant Morale and a Pride of Industry."

Adjournment.

ATTENDANCE

National President R. J. Teetor—President, Cadillac Malleable Iron Co., Cadillac, Mich.

National Vice-President F. J. Walls—Research Development Engineer, International Nickel Co., Detroit.

National Director and Chairman, Chapter Contacts Committee I. R. Wagner—President, Electric Steel Castings Co., Indianapolis, Ind.

National Director W. B. Wallis—President, Pittsburgh Lectromelt Furnace Corp., Pittsburgh.

National Director S. V. Wood—President and Manager, Minneapolis Electric Steel Castings Co., Minneapolis.

Guest Speaker, Ralph Lee—Personnel, General Motors Corp., Detroit.

Guest Speaker, Fred G. Sefing—Research Metallurgist, International Nickel Co., New York.

Guest Speaker, Frank G. Steinebach—Editor, *The Foundry,* Cleveland.

Chapter Officers

BIRMINGHAM—*Secretary-Treasurer* Fred K. Brown—Salesman, Adams, Rowe & Norman, Inc., Birmingham, Ala.

CANTON—*Chairman* R. F. Schmidt—Chief Metallurgist, United Engineering & Foundry Co., Canton, Ohio.

CENTRAL INDIANA—*Chairman* H. H. Lurie—Chief Metallurgist, Cummins Engine Co., Columbus, Ind.

CHESAPEAKE—*Chairman* H. A. Horner—Metallurgist, Frick Co., Waynesboro, Pa.

CHICAGO—*Chairman* A. S. Klopf — Representative, Firegan Sales Co., Chicago.

CINCINNATI—*Chairman* W. A. Rengering—Foundry Superintendent, Cincinnati Milling Machine Co., Cincinnati.

DETROIT—*Chairman* R. G. McElwee—Cast Iron Consultant, Vanadium Corp. of America, Detroit.

EASTERN CANADA & NEWFOUNDLAND — *Vice-Chairman* G. Ewing Tait—Assistant Manager, Roll Foundry Dept., Dominion Engineering Works, Lachine, P. Q.

METROPOLITAN—Fred G. Sefing, International Nickel Co., New York.

MICHIANA—*Chairman* V. C. Bruce—Salesman, Buckeye Products Co., Elkhart, Ind.

NORTHEASTERN OHIO—*President* R. F. Lincoln—President, R. F. Lincoln & Co., Cleveland.

NORTHERN CALIFORNIA—*President* R. C. Noah—Manager, San Francisco Iron Foundry, San Francisco.

NORTHERN ILLINOIS & SOUTHERN WISCONSIN—*Chairman* R. W. Mattison—Vice-President, Mattison Machine Works, Rockford, Ill.

ONTARIO—*Chairman* R. T. Robertson—Malleable Foundry Superintendent, International Harvester Co. of Canada, Hamilton, Ontario.

PHILADELPHIA—*Vice-Chairman* J. M. Robb, Jr.—Sales Representative, Hickman, Williams & Co., Philadelphia.

QUAD CITY—*Chairman* R. E. Wilke—Testing & Research Laboratories, Deere & Co., Moline, Ill.

ROCHESTER—*President* H. B. Hanley—Superintendent, American Laundry Machinery Co., Rochester, N. Y.

SAGINAW SECTION OF DETROIT CHAPTER—*Secretary* H. G. McMurry—Cupola Foreman, Buick Motors Div., General Motors Corp., Flint, Mich.

ST. LOUIS—*Chairman* E. E. Ballard—Plant Engineer, National Bearing Metals Co., St. Louis.

SOUTHERN CALIFORNIA—*President* W. D. Bailey, Jr.—Sales Manager, Westlectric Castings, Inc., Los Angeles, Calif.

TEXAS—*Chairman* F. M. Wittlinger—Secretary, Texas Electric Steel Casting Co., Houston, Texas.

TOLEDO—*Chairman* Leighton M. Long—Consulting Engineer, Leighton M. Long & Associates, Toledo, Ohio.

TWIN CITY—*Chairman* A. M. Fulton, Jr.—Vice-President, Northern Malleable Iron Co., St. Paul, Minn.

WESTERN MICHIGAN—*Chairman* J. L. Brooks—Metallurgist, Muskegon Piston Ring Co., Sparta, Mich.

WESTERN NEW YORK—*Chairman* R. D. Loesch—Treasurer, Lake Erie Foundry Co., Buffalo, N. Y.

WISCONSIN—*President* H. E. Ladwig—Assistant General Superintendent, Allis-Chalmers Mfg. Co., Milwaukee.

A.F.A. Headquarters Staff

Secretary—R. E. Kennedy.

Director, Technical Development Program—N. F. Hindle.

Assistant Treasurer—Jennie Reininga.

Business Manager—Wm. W. Maloney.

Staff Assistant—Leonard Larsen.

2nd Annual Chapter Chairman Conference

Palmer House, Chicago—July 17 and 18, 1945

PROGRAM

Tuesday, July 17

10:00 AM ASSEMBLY AND GETTING ACQUAINTED.

10:30 AM MORNING PROGRAM.

Welcome to Chapter Chairmen.

Introductions.

History and Organization of A.F.A.
A brief background of A.F.A. and its origin, aims and nearly half a century of experience.

The 1945 Year-'Round Foundry Congress.
How A.F.A. service is being carried on in spite of cancellation of the 1945 Convention. The place of AMERICAN FOUNDRYMAN as a medium of information.

Chapter Program Building.
Building a program to serve the members. Why an advance program? Pleasing a diversified group. Aims of the Program Committee. Chapter experience with successful types of programs.

Chapter Organization and Operation.
Requirements for new Chapters. Nomination and election procedures. Rotation of Officers and Directors.

A.F.A. and the Foundry Trade Associations.
The fundamental objects of A.F.A. General functions of A.F.A. as a technical society. The field of the several foundry trade associations.

Conventions and Exhibits.
Selection of a convention city. The 50th Anniversary Foundry Congress and Exhibit.

1:00 PM LUNCHEON.

2:30 PM AFTERNOON PROGRAM.

The Chapters and the National Picture.
The importance of Chapters to A.F.A. work. Influence of National aims on local activities.

Youth Encouragement Committee.
Purpose of the Youth Encouragement Committee. Methods of interesting youth in foundry work. Cooperation with vocational guidance bodies.

Apprentice Training and Student Activities.
What A.F.A. is doing to encourage foundry apprentice training and student interest. Local and national contests. What Chapters can do to promote interest by trade school executives.

Educational Courses.
Advantage of a Chapter-sponsored educational course. Possibilities for support. How the National Office can help.

Cooperation with Engineering Schools and Colleges.
The need for trained engineering personnel. What the schools want from the foundrymen. Trends in engineering education. Scholarships and research projects.

Management Committee.
Combating harmful publicity. Building a pride of industry. Getting the support of foundry management.

Technical Committee Work.
How the A.F.A. Committees operate. The importance of "new blood." Distribution of A.F.A. literature. The A.F.A. foundry library. Recent and forthcoming literature.

4:45 PM ADJOURNMENT OF PROGRAM.

6:30 PM DINNER FOR CHAPTER CHAIRMEN.

Guest Speaker: Dr. Ralph L. Lee, Personnel, General Motors Corp., Detroit.
Subject: "Leadership."

Wednesday, July 18

9:30 AM ASSEMBLY.

Technical Development Program.
The purpose, organization, and work of the Technical Development Program of A.F.A. Its accomplishments during the past year. Support by the industry.

A.F.A. Financing.
Division of the A.F.A. dollar. Sources of National income.

New Dues Structure.
A brief review of the membership structure and its development. Importance of the Secretary and Treasurer in handling dues. The fiscal year and the "member year" . . . present practice.

Chapter Financing.
Some principles of successful Chapter financing. Old and new policy on Chapter refunds. Accumulation of Chapter reserves.

Membership Work.
The A.F.A. membership curve. Present trends in membership. Relationship between various classes of membership. The membership "campaign." The National Membership Committee.

Announcements.

12:00 NOON ADJOURNMENT OF CONFERENCE.

12:00 NOON JOINT LUNCHEON.
Chapter Chairmen and the National Board of Directors.

ATTENDANCE

National President R. J. Teetor—President, Cadillac Malleable Iron Co., Cadillac, Mich.

National Vice-President F. J. Walls—Metallurgist, International Nickel Co., Detroit.

National Director and Chairman of Chapter Contacts Committee S. V. Wood—President and Manager, Minneapolis Electric Steel Castings Co., Minneapolis.

National Director Harry Reitinger—Senior Industrial Engineer, Emerson Engineers, New York.

National Director Ralph T. Rycroft—President, Jewell Alloy & Malleable Co., Buffalo, N. Y.

National Director I. R. Wagner—President, Electric Steel Castings Co., Indianapolis.

National Director W. B. Wallis—President, Pittsburgh Lectromelt Furnace Corp., Pittsburgh.

National Director L. C. Wilson—General Manager, Reading Steel Casting Div., American Chain & Cable Co., Inc., Reading, Pa.

Guest Speaker, Ralph L. Lee—Department of Public Relations, General Motors Corp., Detroit.

Guest, Fred G. Sefing—Research Metallurgist, International Nickel Co., New York.

Guest, Frank G. Steinebach—Editor, *The Foundry,* Cleveland.

Guest, J. W. Wheeler—Consultant to Reynolds Metals Co., Springfield, Mass.

Guest, C. W. Wade—Training Supervisor, Foundry Div., Caterpillar Tractor Co., Peoria, Ill.

Chapter Officers

BIRMINGHAM—*Chairman* J. A. Woody—Assistant Works Manager, American Cast Iron Pipe Co., Birmingham, Ala.

CANTON—*Chairman* H. G. Robertson—Assistant Works Manager, American Steel Foundries, Alliance, Ohio.

CENTRAL INDIANA—*Chairman* Ray S. Davis—Manager, National Malleable & Steel Castings Co., Indianapolis, Ind.

CENTRAL NEW YORK—*Chairman* E. G. White—Plant Engineer, Crouse-Hinds Co., Syracuse, N. Y.

CENTRAL OHIO—*Chairman* T. E. Barlow—Metallurgist, Battelle Memorial Institute, Columbus, Ohio.

CHESAPEAKE—*Chairman* Howard F. Taylor — Metallurgist, Naval Research Laboratory, Anacostia, Washington, D. C. *Secretary-Treasurer* L. H. Denton — Manager, Baltimore Convention Bureau, Baltimore, Md.

CHICAGO—E. R. Young—Climax Molybdenum Co., Chicago.

CINCINNATI—*Chairman* A. W. Schneble—Secretary-Treasurer, The Advance Foundry Co., Dayton, Ohio.

DETROIT—*Chairman* E. C. Hœnicke—Assistant to General Manager, Eaton Mfg. Co., Detroit.

EASTERN CANADA AND NEWFOUNDLAND—*Vice-Chairman* Henri Louette—Assistant Supt., Warden King, Ltd., Montreal, Quebec.

METROPOLITAN—*Chairman* Horace A. Deane—Works Manager, American Brake Shoe Co., New York.

MICHIANA—*Chairman* W. V. Johnson—Superintendent of Pattern Div., Oliver Farm Equipment Co., South Bend, Ind.
Secretary-Treasurer V. S. Spears—Sales Engineer, American Foundry Equipment Co., Mishawaka, Ind.

NORTHEASTERN OHIO—*President* A. C. Denison—President, Fulton Foundry & Machine Co. Inc., Cleveland.

NORTHERN CALIFORNIA—*President* Chas. Hoehn, Jr.—Manager, Foundry Div., Enterprise Engine & Foundry Co., San Francisco.

NORTHERN ILLINOIS AND SOUTHERN WISCONSIN—*Chairman* John R. Cochran—Metallurgist, Sundstrand Machine Tool Co., Rockford, Ill.

NORTHWESTERN PENNSYLVANIA—*Chairman* R. W. Griswold, Jr.—Foundry Superintendent, Griswold Mfg. Co., Erie, Pa.

ONTARIO—*Chairman* T. D. Barnes—Don Barnes Foundry Supplies & Equipment, Hamilton, Ontario.

OREGON—*Chairman* W. R. Pindell—Manager, Northwest Foundry & Furnace Works, Inc., Portland, Ore.

PHILADELPHIA—*Chairman* John M. Robb, Jr.—Resident Manager, Hickman, Williams & Co., Philadelphia.

QUAD CITY—*Chairman* C. E. VonLuhrte—Sales Engineer, Chicago Retort & Fire Brick Co., Davenport, Iowa.

ROCHESTER—*President* Walter F. Morton—Metallurgist, The Anstice Co., Inc., Rochester, N. Y.

SAGINAW VALLEY—*Chairman* H. G. McMurry—Foundry Metallurgist, Buick Motor Div., General Motors Corp., Flint, Mich.

ST. LOUIS—*Chairman* Walter E. Illig—Vice-President, Banner Iron Works, St. Louis.

SOUTHERN CALIFORNIA—*President* R. R. Haley—Owner, Advance Aluminum & Brass Co., Los Angeles.

TEXAS—*Chairman* E. P. Trout—Assistant to President, Lufkin Foundry & Machine Co., Lufkin, Texas.

TOLEDO—*Chairman* N. P. Mahoney—Superintendent, Maumee Malleable Castings Co., Toledo, Ohio.
Secretary-Treasurer Gerald R. Rusk—Salesman, Freeman Supply Co., Toledo.
Director Charles F. Carson—Foundry Superintendent, National Supply Co. of Delaware, Toledo.

TWIN CITY—*Chairman* R. C. Wood—Vice-President, Minneapolis Electric Steel Castings Co., Minneapolis.

WESTERN MICHIGAN—*Chairman* J. Wesley Lee—Vice-President, Challenge Machinery Co., Grand Rapids, Mich.

WESTERN NEW YORK—*Chairman* Arthur H. Suckow—Metallurgist, Symington-Gould Corp., Depew, N. Y.

WISCONSIN—*President* John Bing—District Manager, A. P. Green Fire Brick Co., Milwaukee.
Director R. C. Woodward—Bucyrus-Erie Co., S. Milwaukee, Wis.

A.F.A. Headquarters Staff

Secretary R. E. Kennedy.
Treasurer C. E. Hoyt.
Director, Technical Development Program, N. F. Hindle.
Business Manager Wm. W. Maloney.
Assistant Treasurer Jennie Reininga.
Assistant Editor Gerald R. Buhler.

Minutes of the First Meeting, 1944-45 Board of Directors

Palmer House, Chicago, Ill. July 11 and 12, 1944

1. Presiding: R. J. Teetor

Present: President R. J. Teetor
Vice-President F. J. Walls
Immediate Past President L. C. Wilson
Directors: J. E. Crown
H. S. Simpson
I. R. Wagner
Walton L. Woody
Roy M. Jacobs
Max Kuniansky
W. B. Wallis
S. D. Russell
R. T. Rycroft
Joseph Sully
Past Directors: R. J. Allen
J. G. Coffman
Vaughan Reid
Secretary R. E. Kennedy
Treasurer C. E. Hoyt
Assistant Secretary N. F. Hindle
Assistant Secretary W. W. Maloney
Assistant Treasurer J. Reininga

Absent: D. P. Forbes, F. J. Dost, S. V. Wood, Harry Reitinger.

2. President Teetor upon calling the meeting to order, expressed his appreciation to retiring President Wilson for his helpfulness and cooperation, and also his regret at the loss of the five retiring members of the Board, R. J. Allen, J. G. Coffman, M. J. Gregory, Vaughan Reid, and L. N. Shannon.

3. *Appointment of Nominating Committee*

President Teetor appointed a Nominating Committee consisting of H. S. Simpson, S. D. Russell and J. E. Crown, to present the names of four directors to be elected to the Executive Committee for the coming year, and to place in nomination names for election of Secretary and Treasurer. Director Simpson, as Chairman of the Nominating Committee, presented the following names to be elected to the Executive Committee for 1944-45, and on motion, seconded and carried, they were accepted as members of the Executive Committee for the coming year:

I. R. Wagner
S. V. Wood
L. C. Wilson
W. B. Wallis

4. *Appointment of Standing and Special Committees*

A blanket resolution, authorizing the President to appoint all standing and special committees of the Association, was on motion, seconded, and unanimously carried.

Following this motion, President Teetor announced that the National Membership Committee would be headed by Vice President Fred J. Walls, with the chairmen of all the chapter membership committees serving as members. He further appointed as members of the Board committees, Director Wagner as Chairman of the Chapter Contacts Committee, with Directors Reitinger, Russell, Wallis and Sully serving with him as members, Director D. P. Forbes as Chairman of the AMERICAN FOUNDRYMAN Policy Committee, and Director Max Kuniansky as Chairman of the Technical Activities Correlation Committee.

President Teetor then announced the following appointments to standing Board committees:

Chapter Contacts Committee:
I. R. Wagner, Chairman
J. Sully
H. Reitinger
S. D. Russell
W. B. Wallis
R. T. Rycroft

Youth Encouragement Committee:
F. J. Walls, Chairman
George K. Dreher
A. S. Klopf

AMERICAN FOUNDRYMAN Policy Committee:
D. P. Forbes, Chairman
F. J. Dost
I. R. Wagner
R. J. Allen (Past Board Member)

Management Committee:
S. V. Wood, Chairman
S. D. Russell
F. J. Walls
L. C. Wilson
R. M. Jacobs

Technical Activities Correlation Committee:
Max Kuniansky, Chairman
J. E. Crown
D. P. Forbes
H. Bornstein (Past President)

5. *Discussion of Letter to Engineering Schools*

President Teetor discussed at some length the letter that had been sent out from the national office over his signature to about 800 deans of engineering schools, together with a copy of N. F. Hindle's paper presented before the Society for Promotion of Engineering Education, asking for their guidance in stimulating interest among both the faculty and students in universities in the problems of the foundry industry. He reported that the responses received had been far greater than anticipated, and that although the Committee on Co-operation with Engineering Schools had laid valuable groundwork, there was still a great deal of work to be done in this field. Assistant Secretary Hindle explained how this would receive proper coverage under the Technical Development Program, and described in great detail the educational activities plan and the functions of the different committees.

6. *1944-45 Board Reconvenes*

On reconvening after recessing the meeting, President Teetor opened the meeting by welcoming General T. S. Hammond, past president of the A.F.A. and a member of the Advisory Committee, who gave a short talk on the splendid work that has been done by the foundry industry in this war emergency.

7. *Election of Staff Officers.*

The first business to be acted upon was the election of officers, and Director Simpson, as Chairman of the Nominating Committee, placed in nomination the names of the following to be elected to hold office for the following year:

Secretary, R. E. Kennedy
Treasurer, C. E. Hoyt
Director of Technical Development Program, N. F. Hindle
Business Manager, W. W. Maloney
Assistant Treasurer and Office Manager, J. Reininga

On motion, seconded and carried, these officers were declared elected.

8. *Fixing of Salaries and Compensations*

At this time, the salaried officers were invited to retire from the meeting while Past President L. C. Wilson, Chairman of the Finance Committee, presented recommendations for salaries of these paid officers. The recommendations of the Finance Committee as to the salaries for the paid officers were unanimously approved.

9. *Approval of Resolutions*

The following resolutions were presented, and on motion duly seconded, unanimously approved.

"RESOLVED that resolutions required by the Harris Trust and Savings Bank of Chicago authorizing withdrawal of funds are hereby approved and the Secretary authorized to certify thereto.

"RESOLVED that checks for withdrawal of funds deposited in the name of the Association and withdrawal of all securities in the Awards Fund and in the sinking funds of the Department of Exhibits of the American Foundrymen's Association held by the Trust Department of the Harris Trust and Savings Bank, and the withdrawal of all interest savings accounts of the Association, shall require the signatures of any two of the following officers: President, Vice President, Secretary, Treasurer, or Assistant Treasurer.

"BE IT FURTHER RESOLVED that the Board of Directors authorize a Treasurer's Expense Account of one thousand dollars ($1,000.00), said account to be reconciled at the end of each month by full statement of expenditures; withdrawal checks to be signed by the Secretary, Treasurer, or Assistant Treasurer.

"RESOLVED that the Secretary be authorized to rent a safety box at the Harris Trust and Savings Bank of Chicago for the safekeeping of Association securities and that any two of the following officers, President, Vice President, Secretary, Treasurer, or Assistant Treasurer have authority to obtain access to this box.

"RESOLVED that the Secretary and Treasurer be authorized to reimburse travelling expenses for members in attendance at any regularly called Board of Directors' or committee meeting with the following exceptions: No expenses shall be paid to Directors or committee members for attendance at meetings held during the week of the annual convention of the Association unless specifically authorized by the Executive Committee. When meetings are held in conjunction with other committees or associations the Secretary and Treasurer or the Executive Committee are authorized to determine what portion of the expense of attendance at such meetings shall be paid by the Association.

"RESOLVED that the Officers of the Association are hereby authorized to open a special checking account in the name of the American Foundrymen's Association in the 1945 convention city, they to determine how this account shall be opened and the signatures required for the withdrawal of funds.

"RESOLVED that the present Blanket Position Bond be renewed covering the Secretary, Treasurer, and Assistant Treasurer for five thousand dollars ($5,000.00), each and all other employees for twenty-five hundred dollars ($2,500.00) each, premiums to be paid by the Association."

10. *Technical Development Program Committee*

In accordance with the resolution passed in connection with the adoption of the Technical Development Program, President Teetor appointed an Advisory Committee consisting of three (3) Board members, namely, S. V. Wood, Chairman; Max Kuniansky, and Walton Woody, the additional members of the committee representing the management, technical and operating phases of the branches of the industry to be appointed at a later date.

The following members of the Association were appointed to complete the Advisory Committee of the Technical Development Program:

S. V. Wood, Chairman
Walton Woody, Vice-Chairman
Max Kuniansky, General Manager, Lynchburg Foundry Co., Lynchburg, Va.
D. Basch, Consultant, General Electric Co., Schenectady, N. Y. (Light Metals)
Hyman Bornstein, Director of Laboratories, Deere & Co., Moline, Ill. (Gray Iron and Malleable)
G. K. Dreher, Vice-President in Charge of Manufacturing, Ampco Metal, Inc., Milwaukee, Wis. (Brass and Bronze)
C. J. Freund, Dean of Engineering, University of Detroit, Detroit, Mich. (Education)
James H. Lansing, Consulting Engineer, Malleable Founders' Society, Cleveland, Ohio (Malleable)
F. A. Melmoth, Vice-President in Charge of Operations, Detroit Steel Castings Co., Detroit, Mich. (Steel)
H. S. Simpson, Chairman of the Board, National Engineering Co., Chicago, Ill. (Equipment)

11. *Approval of Budget of Estimated Income and Expense*

Mr. Wilson, as Chairman of the 1944-45 Finance Committee, presented for his committee a proposed budget of estimated income and expenses for the fiscal year ending June 30, 1945, stating that the budget for the current year would be divided into two parts, the first section covering regular activities, and the second section covering special activities, including the Technical Development Program. This budget was discussed in detail, and on motion, seconded, was approved as submitted by the committee.

Upon recommendation by Chairman Wilson that an account in the amount of $25,000.00 be opened in the name of the Technical Development Program, the following resolution was presented, and on motion duly seconded, unanimously approved:

BE IT RESOLVED that the Northern Trust Company of Chicago, Illinois, hereby is designated a depositary in which funds of this corporation may be deposited, and that the Secretary and Treasurer are hereby authorized to open a checking account in said bank in the name of the Technical Development Program of the American Foundrymen's Association, and deposits in this account shall be made from time to time of funds appropriated by the Board of Directors or contributed by companies or individuals for the support of this special activity, and that the Secretary be authorized to execute all bank resolution forms required by the Northern Trust Company, for the opening of this account.

BE IT FURTHER RESOLVED, that checks for withdrawal of funds in this account shall require the signatures of any two of the following officers: President, Vice-President, Secretary, Treasurer, and Assistant Treasurer.

12. *Dues Structure*

Attention was directed by Mr. Simpson to the fact that the income derived from exhibits in the years in which exhibits were held often exceeded the receipts from dues income, and together with the fact that the service A.F.A. is giving to its members far exceeds the amount of dues collected, he recommended that the dues structure should be changed. After much discussion, the Board recommended that the Executive

Committee be directed to reinstate action taken at the Board of Directors' meeting on July 19, 1942, toward increasing dues.

Motion was made by H. S. Simpson that dues should be increased, and that a directive be given the Executive Committee to work out a proper structure, giving primary consideration to the raising of Company Memberships to $50.00 and Sustaining Membership to $100.00. Motion seconded, and carried.

13. *Management and Youth Encouragement Committees*

The Board approved going ahead with the Management Committee and Youth Encouragement Committee, as recommended by the Technical Activities Correlation Committee, and President Teetor appointed S. V. Wood as Chairman of the Management Committee, and Fred J. Walls as Chairman of the Youth Encouragement Committee.

14. *Heat Transfer Committee*

The Board also approved the Heat Transfer Project, as recommended by the Technical Activities Correlation Committee, and the appropriation of the necessary funds was referred to the Finance Committee.

15. *1945 and 1946 Conventions*

W. W. Maloney reported on the convention city for 1945, reviewing conversations held with Chapter Officers and Convention Bureau representatives at Milwaukee, Detroit, and Pittsburgh, with reference to hotel accommodations available for an estimated attendance of 3,000, and preliminary conversations with the Stevens Hotel, Chicago. He read a letter received from Harry Ladwig, Chairman of the Wisconsin Chapter, which stated that if Milwaukee was being considered as the 1945 Convention City, they must have a decision by August 1st, so that if their invitation was not accepted, they could go ahead with their plans for the annual Regional Conference to be held in Milwaukee in February. A recommendation was presented that in view of the lack of time, a letter should be written to the Wisconsin Chapter thanking them for their invitation, but stating that, due to the circumstances, the 1945 convention would not be held in Milwaukee. On motion, seconded, it was unanimously carried.

Mr. Maloney also brought up the necessity for making a decision in regard to the 1946 Convention City, stating that it was hoped that this would be both an annual meeting and an international congress, and inasmuch as most of the exhibit halls have been taken over by government services, and that so many associations are planning on conventions in 1946, it was imperative that a decision be made at an early date so that commitments on dates and exhibit halls might be made.

After discussion, Director Wagner made a motion as follows:

> "That the Board refer the matter of the dates and locations of the next two conventions back to the Executive Committee for their consideration, and further report to the Board for decision by letter ballot, with authorization to make tentative arrangements for necessary commitments of dates and places."

Motion seconded by Director Sully and carried.

18. *Preconvention Issue*—AMERICAN FOUNDRYMAN

Director I. R. Wagner made a motion as follows:

> "That the publication of the 1945 Preconvention Issue of the AMERICAN FOUNDRYMAN is authorized on the same basis as that of the 1944 Issue."

Motion was seconded by Director Wallis and carried.

There being no further business to come before the Board at this time, the meeting on motion was adjourned.

Respectfully submitted,

R. E. KENNEDY,
Secretary.

Minutes of the Executive Committee Meeting

Hotel Statler, Cleveland—Tuesday, October 17, 1944

1. Present: President R. J. Teetor
Vice President F. J. Walls
Directors: W. B. Wallis
I. R. Wagner
L. C. Wilson
S. V. Wood
Treasurer C. E. Hoyt
Secretary R. E. Kennedy
Technical Development Director N. F. Hindle
Business Manager W. W. Maloney

2. *Reading of Minutes*

The meeting was called to order by President Teetor at 10 a.m., with W. W. Maloney reading the Minutes of the previous Executive Committee meeting held June 20th and the July Board of Directors meeting. On motion, seconded, the Minutes of the Executive Committee were approved as read.

3. *Report of Treasurer*

Treasurer Hoyt presented a comparative report for the first quarter of the current fiscal year, correlating the Association's position with similar periods during the past five years. This report showed that collections of dues as of September 30 have already exceeded the dues budget for the entire year, and also showed a cash position exceeding any similar period since 1939.

4. *Technical Development Program*

Authorization was given for extending to the entire industry the opportunity of aiding the new Technical Development Program in its essential work. To this end a motion was made by Director Wood, seconded by Director Wilson, and carried,

> "That general solicitation for the Technical Development Program be expanded so that the opportunity can be offered other firms without limitation to contribute to the Program for its continuation and development."

It was the consensus of opinion of the Executive Committee that any contributions in the form of endowments to the Technical Development Program would be acceptable.

Motion was made by Director Wallis, seconded by Director Wagner, and carried,

> "That the sum of $2,500.00 be advanced from the A.F.A. general funds for extending to the industry the opportunity of contributing to the Technical Development Program."

It was the consensus of opinion that the A.F.A. general fund should be reimbursed for the $2,500.00 thus advanced, at the end of the current fiscal year.

5. *Special Publications*

Following the discussion on gratis distribution to members of special publications of the Technical Development Program, motion was made by Director Wallis, seconded by Director Wilson, and carried,

> "That the Technical Development Program be reimbursed from A.F.A. general funds for all copies of the Cast Metals Handbook furnished members gratis, on the basis of the actual cost of such books to the Technical Development Program."

A further motion was made by Director Wallis, seconded by Director Wagner, and carried,

> "That the Technical Development Program be reimbursed for all copies of the Sand Testing Handbook furnished members gratis, on the basis of the actual cost of the books to the Technical Development Program."

It was understood that the term "actual cost" in the above resolutions refers to the actual "out-of-pocket cost" and not to any expense incurred by the Association as a whole prior to the time the accounts for these special publications were transferred to the Technical Development Program budget.

Particular discussion was held with reference to gratis distribution to members of the Sand Testing Handbook, following which a motion was made by Director Wallis, seconded by Vice-President Walls, and carried,

> "That members be notified that the Sand Testing Handbook will be ready for distribution soon, that members desiring their member copy should order same prior to a stated date, after which date a price will be charged for all copies distributed."

6. *Chapter Contact Conference*

Director Wagner as Chairman of the Chapter Contact Committee of the Board, in reporting on the Chapter Contact Conference held August 26, in Chicago, stated that the meeting had proved an unqualified successs, with 26 of the 27 Chapters represented. Of the Chapter representatives present, 21 were Chairmen, 2 Vice-Chairmen, 2 Secretaries, and one guest representative. He reported that total expense of the meeting was approximately $2,000 against a budgeted amount of $2,500.00.

Due to its extreme success Chairman Wagner recommended that the Conference be made an annual event and a two-day meeting. Motion then was made by Director Wallis, seconded by Director Wagner, and carried,

> "That it be recommended to the Board of Directors that funds be appropriated for a 1945 Chapter Conference of two days and that consideration be given to holding the Conference during the week of the annual Board meeting in July."

Director Wagner was authorized to work out with the Staff a proper schedule of attendance, both by National Officers and Staff members, at "National Officers' Nights" of the various Chapters.

7. *Cupola Research Project*

Following discussion of the status of funds administered by A.F.A. on behalf of the Cupola Research Project, a recommendation was made by Director Wilson without motion that the Steering Committee of the Cupola Research Project be approached in the matter of transfer of the balance of Cupola Research funds into the Technical Development Program funds, with the understanding that such Cupola Research funds would continue to be earmarked for that project alone.

8. *1945 Convention City*

Business Manager Maloney reported the selection of Detroit as the 1945 Convention City, folowing letter ballot approval by the Board of Directors, with the meeting scheduled for the week of April 30-May 4.

9. *1945 Nominating Committee*

In accordance with the procedure prescribed in the revised By-Laws effective July 1, 1944, appointees for the 1945 Nominating Committee were considered, including names submitted by Chapter Boards of Directors to serve with the last two Past Presidents of A.F.A. The following Committee, showing Chapter area and section of industry represented, was appointed:

Past President D. P. Forbes, Gunite Foundries, Inc., Rockford, Ill.

Past President L. C. Wilson, Reading Steel Casting Div., American Chain & Cable Co., Reading, Pa.

W. E. Mahin, Armour Research Foundation, Chicago, Ill. (Representing Gray Iron)

Charles Morrison, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich. (Saginaw Valley; Representing Malleable)

M. J. Lefler, Strom Brass Foundry, Elkhart, Ind. (Michiana Chapter; Representing Non-Ferrous)

R. K. Glass, Republic Steel Corp., Buffalo, N. Y. (Western New York Chapter; Representing Equipment)

Edw. Trout, Lufkin Foundry & Machine Co., Lufkin, Texas (Texas Chapter; Representing Gray Iron)

Henry McFarlin, The Lunkenheimer Co., Cincinnati, Ohio (Cincinnati Chapter; Representing Non-Ferrous)

J. W. Porter, American Steel Foundries, East Chicago, Ind. (Chicago Chapter; Representing Steel)

On motion by Vice-President Walls, seconded by Director Wilson, and carried, Past President D. P. Forbes was designated the Chairman of the 1945 Nominating Committee.

10. *Membership Dues*

Extensive discussion was held in connection with the directive issued at the Board meeting in July toward increasing dues. The suggestion was made that a definite decision be made by the Executive Committee at a meeting to be held the day prior to the January, 1945, Board meeting. A motion then was made by Director Wallis, seconded by Director Wagner, and carried,

> "That a committee of three members of the Executive Committee be appointed to obtain additional data on the question of dues structure and report back to the Executive Committee at the January meeting."

Accordingly, President Teetor appointed the following special committee on dues: Vice-President Walls, Directors Wagner and Wallis.

President Teetor anounced that the next meeting of the Executive Committee would be held Tuesday, January 16, 1945, and that the Mid-Year meeting of the Board of Directors would convene on Wednesday, January 17.

11. *Membership Report*

A report on A.F.A. membership was submitted by Vice President Walls, as Chairman of the National Membership Committee, showing the following:

Membership as of June 30, 1944	6,620
Membership as of October 16, 1944	6,922
Sustaining Members as of October 16, 1944	224

(Increase of 53 Sustaining Members since June 30.)

12. *Youth Encouragement Program*

Vice-President Walls, as Chairman of the Youth Encouragement Committee, outlined the elements of a program proposed to two companies in the Detroit area and described some of the causes of present personnel conditions in the foundries.

13. *Management Program*

Director Wood, as Chairman of the Management Committee, brought out the need for action in obtaining greater interest on the part of foundry management in the activity of A.F.A. Following discussion, authorization was given for holding several Management Meetings during the current year in conjunction with Association Chapters with the dual purpose of selling management on the benefits to be derived from A.F.A. activities and building a greater pride of industry on the part of foundry owners and managers.

14. *Joint Welding Committee*

Vice-President Walls described talks he has held with American Welding Society officials, in connection with a Joint Committee on welding of castings. Authorization was given Vice-President Walls to proceed this matter to conclusion as the official A.F.A. representative.

15. On motion, seconded, the meeting was adjourned.

Respectfully submitted,

R. E. KENNEDY,
Secretary.

Minutes of the Executive Committee Meeting

Palmer House, Chicago, Ill. January 16, 1945

1. Present: President R. J. Teetor
Vice President F. J. Walls
Directors: W. B. Wallis
I. R. Wagner
L. C. Wilson
S. V. Wood
Treasurer C. E. Hoyt
Secretary R. E. Kennedy
Technical Development Director N. F. Hindle
Business Manager W. W. Maloney

2. *Reading of Minutes*

The meeting was called to order by President Teetor at 2 P. M. and at his suggestion the reading of the minutes of the October 17th, 1944, meeting were dispensed with, having been submitted by mail and approved.

3. *Report on Membership*

The report on membership was presented by Vice-President Walls, Chairman of the National Membership Committee. He stated that 1,054 new members had been enrolled during the year and that book membership as of December 31, 1944, was 7,194, with a decided increase in Sustaining and Company members. President Teetor commended Chairman Walls on this fine report, stating that the increase in new members had far exceeded the expectations for 1944.

On motion, seconded, and carried, the report was approved.

4. *Report on Finances*

Treasurer Hoyt presented the Budget Report for the first six months of the fiscal year together with detailed statement showing Receipts and Disbursements. He called particular attention to comparative figures on dues income for the years 1941 to 1944, and gave a brief summarization of the report.

In reviewing the Technical Development Program budget for 1944-45, Treasurer Hoyt recommended that the budget be revised and submitted to the Finance Committee for approval. It was moved by Director Wilson, seconded by Vice-President Walls, and carried:

> "That the current year's budget be revised in conjunction with the Advisory Committee of the Technical Development Program and submitted to the Finance Committee for approval."

On motion, seconded, and carried, the Finance Report was approved.

5. *Report on Contributions to Technical Development Program*

President Teetor announced that due to the illness of W. H. Alexander of Ashcraft and Ashcraft, Attorneys, he would not be present to discuss deductibility of contributions to the Technical Development Program from income tax. The question of classification of the American Foundrymen's Association by the Internal Revenue Dept. was discussed; and it was moved by Vice-President Walls, seconded by Director Wilson, and unanimously carried:

> "That the necessary steps be taken to clarify the classification of the American Foundrymen's Association with the Internal Revenue Department."

An informal report was presented by Treasurer Hoyt on Technical Development Program contributions to date, and it was pointed out that a number of companies had requested more specific information on the size of contributions that might be expected from their size and type of company. Director Wilson recommended that solicitation for Technical Development funds be continued at least throughout the current year.

6. *Report on Conference with Ordnance Department*

President Teetor reported on the Washington conference, to which he, Vice-President Walls, and Secretary Kennedy were invited at the request of the Ordnance Department, to formulate plans to cooperate with the Ordnance Department through an A.F.A. committee whose services would be available to the research and development department for consultation on matters concerning the foundry industry.

President Teetor suggested that five 5-man committees be appointed, representing the different divisions, with the chairman of each committee forming a general committee of five to work with the Ordnance Department, with one man as liaison to attend general meetings, and that this recommendation be submitted for the Board's approval.

1945 Foundry Congress

Plans for holding the 4th War Production Foundry Congress in Detroit April 30th to May 4 were reconsidered in light of the January 3 appeal by the government for restriction of conventions in order to conserve transportation and hotel facilities.

Business Manager Maloney reviewed events following the government appeal and pointed out that any group desiring to hold a meeting of more than 50 people after February 1 was required to obtain approval by a Committee on Wartime Conventions under Director of War Mobilization James F. Byrnes. In view of these developments, the entire question of holding the 1945 Convention was reconsidered. It was felt that whatever action was taken by A.F.A. with regard to this meeting, should be based on its contribution to the war effort and whether or not such action could be questioned by the membership of the industry or by the government.

Accordingly, an alternate program of activities was presented in lieu of the Detroit meeting, consisting of the following five proposals:

"1. That the 1945 Foundry Congress, scheduled for Detroit, April 30-May 4, be voluntarily cancelled, in compliance with the Government's appeal.

"2. That a 'Year-'Round Foundry Congress' be substituted in lieu of the announced Detroit Foundry Congress, so that technical papers, reports and discussions can continue to be disseminated to the industry in accordance with the Association's obligations. It is expected that papers and discussions can thus be solicited and published throughout the year.

"3. That the Quarterly 'Transactions' be suspended as an emergency expedient, and all papers and discussions ordinarily printed in the Quarterly be published in AMERICAN FOUNDRYMAN monthly as the proceedings of the 'Year-'Round Foundry Congress,' beginning in May, 1945. Recent increases in paper allotments should make this possible. No change is contemplated in issuance of Bound Volume.

"4. That the issuance of Preprints be suspended in 1945, as an emergency expedient and because of the proposed cancellation of the Detroit Foundry Congress. Since the main purpose of Preprints is to induce discussion of convention papers, that purpose will be fully accomplished by their publication in AMERICAN FOUNDRYMAN.

"5. That plans for the Pre-Convention (April, 1945) Issue of AMERICAN FOUNDRYMAN be revised, to provide for a 'Year-'Round Congress Issue' in May, with advertising accepted in this and succeeding monthly issues containing Transactions and Preprint material. While it has been previously stated that paper restrictions would not permit this plan, recent paper increases granted AMERICAN FOUNDRYMAN should make possible acceptance of advertising on a limited scale. Opportunity would be given those who have reserved space in the Pre-Convention Issue, to designate their choice

of issues carrying Transactions and Preprint material."

Following presentation of the five-point alternate program, motion was made by Director Wallis, seconded by Director Wilson, and unanimously approved:

"That the program be submitted in entirety for approval by the Board."

Report of Special Subcommittee on Dues Structure

The report of the Special Subcommittee on Dues Structure, appointed at the October 17, 1944, meeting was submitted. This subcommittee, charged with the specific duty of recommending dues increases, as authorized by the By-Laws, offered the following proposal:

1. That Sustaining Membership dues be increased to a minimum of $100.00 annually, and that Company Membership dues be increased to $50.00 annually.

While this recommendation covered the specific task of the subcommittee, two additional recommendations were submitted, because of the importance of dues income to overall financing of A.F.A., as follows:

2. That the By-Laws be amended to increase the chapter refund to a straight maximum of 20%.
3. That 75% of the income from increased dues be allocated to the Technical Development Program, and 25% to regular A.F.A. activities.

In discussing these recommendations, the subcommittee referred to a 17-page report of the subcommittee meeting held November 14th in Chicago. In this report it was pointed out that the possibility of increasing dues had been discussed in recent months before several chapters, with no specifically negative reactions.

The question of an increase in the chapter refund was discussed at length, especially the refund on $8.00 personal membership. While some differences of opinion were presented on this point, it was agreed that an increase in the chapter refund would be most desirable, the specific amount or per cent to be left to the Board of Directors.

In the belief that the subcommittee's recommendations on increased dues and on chapter refunds formed a sound basis for Board discussion, Vice-President Walls moved:

"That this portion of the Subcommittee's report be accepted and submitted to the Board of Directors for final approval."

Motion seconded by Director Wood and unanimously carried.

Some disagreement was expressed with reference to allocation of a percentage of the increased dues to the Technical Development Program. It was agreed, however, that continuous financing of the Technical Development Program might be materially helped by the recommended increases in dues. Since no agreement was reached on the allotment of specific percentages of the increased dues to the Technical Development Program, it was decided that this portion of the Subcommittee's recommendations should be presented to the Board in the form of a suggestion for Board discussion.

Increase in Salary Budget

Secretary Kennedy presented a request for an increase of $25,000 in the present salary budget, in order to better serve the increased number of chapters, and to provide such additional personnel required under present programs. After discussion, it was moved, seconded, and carried:

"That the Executive Committee recommend to the Board authorization for such an increase, at the discretion of the Secretary."

Respectfully submitted,
R. E. KENNEDY,
Secretary.

Minutes of Meeting, Board of Directors

Palmer House, Chicago, Ill. January 17, 1945

1. Present: Vice-President Fred J. Walls, presiding

Directors:	J. E. Crown	Max Kuniansky
	H. S. Simpson	W. B. Wallis
	I. R. Wagner	F. J. Dost
	S. V. Wood	S. D. Russell
	Walton L. Woody	R. T. Rycroft
	D. P. Forbes	Joseph Sully
	Roy M. Jacobs	L. C. Wilson

Absent: President Ralph J. Teetor

2. *Minutes of Previous Meetings*

The minutes of the Board meeting held July 11 and 12, 1944, were read and on motion by Director Kuniansky, seconded by Director Reitinger, were approved.

The minutes of the Executive Committee meeting held October 17, 1944, were read and, on motion, seconded, were approved.

3. *Report of 1945 Nominating Committee*

Chairman Forbes reported that the 1945 Nominating Committee had nominated the following for Officers and Directors:

President (to serve 1 year)
Fred J. Walls, Metallurgist, International Nickel Co., Detroit, Mich.

Vice-President (to serve 1 year)
S. V. Wood, President, Minneapolis Electric Steel Casting Co., Minneapolis, Minn.

Directors (to serve 3 years)
F. M. Wittlinger, Secretary, Texas Electric Steel Co., Houston, Texas

James H. Smith, Works Manager, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

H. H. Judson, Superintendent, Gould Pumps, Inc., Seneca Falls, N. Y.

George K. Dreher, Vice-President in Charge of Manufacturing, Ampco Metal Inc., Milwaukee, Wis.

E. W. Horlebein, President, Gibson & Kirk Co., Baltimore, Md.

Director (as immediate Past President to serve 1 year in accordance with By-Laws revised effective July 1, 1944)
Ralph J. Teetor, President, Cadillac Malleable Iron Co., Cadillac, Mich.

In accordance with Article X, Section 8, of the By-Laws, it was announced that the Secretary would publish the report of the Nominating Committee to all members of the Association "at least 60 days before the annual Business Meeting."

4. *Report of Board of Awards*

The report of the January 16th meeting of the 1945 Board of Awards was presented by Chairman Wilson, who announced that two Gold Medals of A.F.A. had been awarded as follows:

The John A. Penton Gold Medal to Clarence E. Sims, Battelle Memorial Institute, Columbus, Ohio—

"Because of his outstanding contribution to American Foundrymen's Association and to the steel casting industry."

The Joseph S. Seaman Gold Medal to R. E. Kennedy, Secretary of the American Foundrymen's Association—

"For outstanding meritorious service to all branches of the foundry industry through his work in organizing and guiding the development of technical and operating papers and discussions, and in his untiring

encouragement to all A.F.A. chapters, committees and members."

Chairman Wilson also reported that Honorary Life Memberships had been voted for presentation to the following:

Rear Admiral A. H. Van Keuren, U.S.N., Director of Naval Research Laboratory, Washington, D. C.—

"In recognition of his efforts and interest in behalf of the foundry industry, and his cooperation with the foundry industry in research work."

M. J. Gregory, Retired (formerly of Caterpillar Tractor Company, Peoria, Ill.)—

"For his contribution to the Association and the foundry industry."

Ralph J. Teetor, as retiring President of the A.F.A.

C. E. Sims and R. E. Kennedy as 1945 Medallists.

Following presentation of this report, Director Simpson moved that the action of the Board of Awards be approved. Motion seconded by Director Reitinger and unanimously carried.

5. *1945 Foundry Congress*

At the request of Chairman Walls, a progress report on the 1945 Foundry Congress was presented by Business Manager Maloney, particularly tracing the developments since January 1. It was brought out that the program for the Detroit Foundry Congress was far advanced by the first of the year, but that plans for this meeting had had to be reconsidered following the announcement on January 3 of the government appeal for restriction of wartime conventions. This appeal stressed the urgency of conserving transportation and hotel facilities, resulting in formulation of a government committee on Wartime Conventions on January 5, under which all meetings of over 50 people held after February 1 were required to be approved by the committee.

In view of the advanced plans for the Detroit meeting, and of advertising reservations for the Preconvention Issue of the AMERICAN FOUNDRYMAN, it was brought out that a delay in obtaining government approval for the 1945 meeting would be most serious. It was realized that any Foundry Congress, even in curtailed form, would make large use of rail and hotel accommodations, and that A.F.A., as a leader in the industry, should probably take such action as could not be questioned by anyone.

It was reported that the entire question had been carefully considered by the Executive Committee in session January 16, particularly on the basis of what course would best serve the war effort. At that meeting it was felt that even if A.F.A. had to depart from its usual program of activities, it should not hesitate to adapt itself so as to meet wartime conditions in a manner consistent with its policies and services.

Accordingly, the following recommendation of the Executive Committee was presented:

"That the 1945 Congress scheduled for April 30 to May 4 be voluntarily cancelled in compliance with the government appeal."

On motion by Director Simpson, seconded by Director Jacobs, the above proposal of the Executive Committee was unanimously approved.

At the suggestion of Director Wilson, a telegram was read addressed to Director of War Mobilization, James F. Byrnes, over the signature of President Teetor, as follows:

"Notwithstanding the virtual completion of plans for the 49th Annual Meeting and the Fourth War Production Foundry Congress of the American Foundrymen's Association, our Board of Directors has voted to cancel this meeting nationally announced for April 30 - May 4 in Detroit. While the national meetings of the American Foundrymen's Association are directed primarily to aiding the more effective production of castings for war purposes, we believe that these purposes may be affected through processes involving no large gatherings and through the full utilization of avenues now open for consultation with Army and Navy Ordnance. The Association will continue and extend the work in the interest of war production through every available means. Recognizing the necessity for minimizing travel during this crisis, we are in full accord with your program and unanimously subscribe to your request."

On motion of Director Simpson, seconded by Director Jacobs, the above telegram was included as part of the original motion.

Recommendation of the Executive Committee for an alternate program of 1945 activities, in lieu of cancellation of the Detroit Convention, was presented as follows:

"That a 'Year-'Round Foundry Congress' be substituted in lieu of the announced Detroit Foundry Congress, so that technical papers, reports and discussions can continue to be disseminated to the industry in accordance with the Association's obligation. It is expected that papers and discussions can thus be solicited and published throughout the year.

"That the Quarterly 'Transactions' be suspended, as an emergency expedient, and all papers and discussions ordinarily printed in the Quarterly be published in AMERICAN FOUNDRYMAN monthly as the proceedings of the 'Year-'Round Foundry Congress,' beginning in May, 1945. Recent increases in paper allotments should make this possible. No change is contemplated in the issuance of the Bound Volume.

"That the issuance of Preprints be suspended in 1945, as an emergency expedient and because of the proposed cancelation of the Detroit Foundry Congress. Since the main purpose of Preprints is to induce discussion of convention papers, that purpose will be fully accomplished by their publication in AMERICAN FOUNDRYMAN.

"That plans for the Pre-Convention (April, 1945) Issue of AMERICAN FOUNDRYMAN be revised to provide for a 'Year-'Round Congress Issue' in May, with advertising accepted in this and succeeding monthly issues containing Transactions and Preprint material. While it has been previously stated that paper restrictions would not permit this plan, recent paper increases granted AMERICAN FOUNDRYMAN should make possible acceptance of advertising on a limited scale. Opportunity would be given those who have reserved space in the Pre-Convention Issue to designate their choice of issues carrying Transactions and Preprint material."

In discussion on the alternate program, Director Forbes suggested that the authors of papers intended for the Detroit meeting might be asked to present their papers before chapter meetings. Chairman Walls stated that it also was intended to publish the papers and written discussions simultaneously in issues of the AMERICAN FOUNDRYMAN. Secretary Kennedy suggested that reprints thus published might be utilized for discussion purposes in the chapters.

Director Forbes also suggested that something in the form of a symposium might be worked out for chapter meetings somewhat in the form of "little conventions." Director Dost offered the thought that such local meetings might prove to be a big drawing card for local chapter attendance. Director Kuniansky suggested that the Shop Operation Courses might be squared down to chapter size, so as to present at chapter meetings more material of practical benefit to local shop men.

In connection with the proposal to accept advertising in eight regular 1945 issues of the AMERICAN FOUNDRYMAN, in lieu of the Preconvention Issue, Director Simpson expressed disapproval of this proposal and suggested instead that advertising be confined to an "Annual Review Number." Director Wallis, in expressing approval of the advertising proposal, registered disapproval of a single advertising issue.

Director Wilson declared that publication of the "Transactions" and similar material in monthly issues of the AMERICAN FOUNDRYMAN would greatly extend the magazine's reader interest, and expressed his opinion that this editorial material would make the AMERICAN FOUNDRYMAN of greater value to advertisers than a Preconvention Issue. Director Kuniansky pointed out that in previous discussions on improving the AMERICAN FOUNDRYMAN, the question of advertising in monthly issues had been recommended and he suggested that the

emergency program proposed would make possible trying out such a recommendation. Director Wagner recalled the lengthy report of the 1944 American Foundryman Policy Committee presented before the Board last July, recommending a similar policy on advertising.

Director Simpson suggested that the opinion of advertisers be obtained with regard to the proposed 1945 policy for the AMERICAN FOUNDRYMAN. Director Wilson pointed out that, since all advertisers in the 1945 Preconvention Issue were to be approached in connection with the proposed policy, the response therefrom would serve that purpose. Director Forbes stated that over a number of years, members of A.F.A. had recommended advertising in regular issues of the AMERICAN FOUNDRYMAN for the additional information that would be provided, and for improvement of the Association's monthly magazine.

At the request of Chairman Walls, Business Manager Maloney stated that WPB paper restrictions would materially limit the number of advertising pages that could be made available in any one issue of AMERICAN FOUNDRYMAN, and that the maximum of such pages would probably average 50 to 60 per issue. It was pointed out that a number of voluntary requests for advertising space are received every year for regular issues of the AMERICAN FOUNDRYMAN.

The necessity for some form of prompt decision was emphasized by Chairman Walls and Director Wilson, so that advertisers in the Preconvention Issue might be advised immediately of Board action, and that immediate provision be made for bringing to the membership a continuous flow of technical and practical data. Director Russell expressed approval of the proposed AMERICAN FOUNDRYMAN policy as a means of producing a better magazine for the membership. Director Kuniansky declared that the presence of advertising would increase the interest of men in the shop in their Association publication.

Following discussion, the proposed alternate program as recommended by the Executive Committee on motion was seconded and unanimously approved.

6. *1946 Foundry Congress*

Plans for the 50th Anniversary Foundry Congress scheduled for 1946 were discussed in light of present government restrictions on conventions. Business Manager Maloney reviewed previous steps taken thus far in determining a time and place and stated that tentative commitments had been made for both Cleveland and Philadelphia for May, 1946.

In view of the possible necessity for postponement next year, Director Woody moved that these tentative commitments also include provisions for dates in October, 1946, as well as May. Motion seconded by Director Simpson and carried.

7. *Report of Finance Committee*

Chairman Wilson called on Treasurer Hoyt to give the Treasurer's report and an explanation of the budget and financial statement. Chairman Wilson further stated that the Technical Development Advisory Committee were being asked to submit a revised budget to bring it in line with their present operations.

On motion, seconded, the report was unanimously accepted.

8. *Report of Membership Committee*

Chairman Walls briefly reviewed the Membership Report, which showed an enrollment of approximately 1,054 new members during the year, making the book membership 7,194 as of December 31, with a decided increase in Sustaining and Company members.

On motion, seconded, and carried, the report was unanimously accepted.

9. *Report of Chapter Contact Committee*

Chairman Wagner briefly commented on the success of the 1944 Chapter Chairman Conference, and stated that a recommendation had been made that this conference be repeated in 1945, extending the time to a two-day meeting. He also discussed the new chapters, Central Ohio being the newest chapter, with Portland in the process of organization. He stated that chapter visitations by officers and directors had been very successful and had resulted in great value to both the chapters and the Association in securing better support from management.

A discussion of chapter activities in different parts of the country followed this report, in which Directors Reitinger, Sully, Russell, and Jacobs participated, and it was the consensus of opinion that all the chapters were self-supporting and in good financial condition.

10. *Report on Management Committee*

Chairman Wood, in reporting on his committee, stated that an effort had been made to acquaint top management with the activities of the A.F.A., and as an experiment a luncheon was held in Minneapolis to which only high executives were invited. The sole purpose of the luncheon was to impress upon management the value of the A.F.A. The meeting was very successful and Chairman Wood stated that more of these meetings would be held in the future, in different chapter areas.

11. *Death of William H. Schulte*

Mr. Hoyt announced the sudden death of Bill Schulte of the National Engineering Co., Chicago, who was very well known to foundrymen and exhibitors, as superintendent of exhibit installation for the A.F.A. for 35 years. Mr. Hoyt expressed not only a deep personal loss, but stated that Mr. Schulte's death would be keenly felt by the entire industry.

12. *Dues Structure*

In accordance with the directive issued by the Board of Directors at the July, 1944, meeting, the Executive Committee presented recommendations for increasing membership dues. The recommendation, embodying the findings in a 17-page report of a Special Subcommittee on Dues Structure, was in four parts as follows:

(a) Sustaining Members shall pay minimum annual dues of $100. (A company or organization may pay more than the minimum dues of $100.00 in proportion to the benefits the company or organization may feel accruing and to its desire to further the aims and purposes of the Association.)

(b) Company Members shall pay annual dues of $50. (It shall be understood that Company Membership privileges shall apply only to the plant or general office of an organization where said membership is held.)

(c) That Section 4 of Article XVI (Local Chapters) be amended to read as follows: "For financing of each local Chapter, the Board of Directors may authorize an appropriation not to exceed twenty per cent (20%) of the annual dues received from members of each Chapter."

(d) That 75% of the net income derived from the increased dues recommended herein be allocated to the Technical Development Program, and 25% to the Regular activities of A.F.A. in accordance with the schedule.

Chairman Walls pointed out that the recommended increases in Company and Sustaining dues fully discharged the duty of the Executive Committee. He explained that the other two recommendations were included because dues income directly concerned the overall financing of A.F.A. and the chapters, and also may be considered to play a large part in year by year financing of other A.F.A. activities.

Lengthy discussion of many phases of the dues structure followed. Points considered included: (a) Average income per sustaining membership, (b) Difference between company and sustaining membership, (c) Estimated effects of raising company and sustaining dues, (d) Estimated effects of possible losses due to post-war conditions, (e) Membership rates of other technical societies, (f) Per cent of total dues income from each member class, (g) Sliding scales for company and sustaining dues, (h) Cost of servicing an A.F.A. membership, (i) Number of affiliates per company and sustaining membership, etc.

Chairman Walls pointed out that in considering the dues structure it was felt, first of all, that no increase should be made in the dues of Personal members since all A.F.A. memberships are held by individuals and since the individual

and his activity forms the backbone of A.F.A. work. It was also believed that no company should be penalized for its judgment in utilizing the affiliate privilege to the fullest.

On motion by Director Simpson, seconded by Director Kuniansky and unanimously carried, it was voted to increase Sustaining Membership dues to a minimum of $100.00 annually, effective July 1, 1945.

On motion by Director Jacobs, seconded by Director Simpson, and carried unanimously it was voted to increase Company membership dues to $50.00 annually, effective July 1, 1945.

In discussion of the Executive Committee's recommendation that the refund to chapters be increased to a straight 20%, it was felt that the chapters quite properly should share in the increased dues voted. It was brought out that an increase in the refund would be of material assistance in chapter financing and might also stimulate local educational programs.

At present the chapter refunds are as follows: $2.00 on each $8.00 membership; $3.00 on each $15.00 membership; $5.00 on each $25.00 membership, and a maximum of $10.00 on each sustaining membership of $50.00 or more. The recommendation of the Executive Committee proposed the following 20% refunds: $1.60 on each $8.00 membership; $3.00 (as now) on the $15.00 class; $10.00 on each $50.00 company membership (new dues rate); 20% on each sustaining membership of $100.00 or more (new dues rate).

Motion was made, seconded, and carried, that the Board authorize a maximum refund to 20%, and that consideration be given to amending Article XVI, Section 4, of the By-Laws at a later date, so as to bring this section up-to-date in accordance with the Board action.

Considerable discussion took place on the suggestion by the Executive Committee that the Board consider allocating some definite percentage of the expected increased dues income for continuous financing of the Technical Development Program. The consensus of Board opinion was that no definite percentage should be set up in advance, but that funds for the Technical Development Program should be voted by the Board on the basis of budgets submitted for each year's activities, the same as for budgets covering regular activities of the Association.

It was considered an obligation of the Finance Committee to pass upon Technical Development Program budgets submitted for recommendation to each succeeding Board of Directors. It was agreed that any new membership received up to the date of July 1, 1945, the date on which the new dues would become effective, would be accepted at the rates at present in effect for one full year.

13. *Increase in Salary Budget.*

The recommendation of the Executive Committee that the annual salary budget be increased to take care of additional personnel needed for expanded activities was discussed, and on motion by Director Simpson, seconded by Director Kuniansky, it was unanimously carried:

> "That the recommendation of the Executive Committee relative to the increase of $25,000 in the annual salary budget be approved."

14. *1945 Chapter Chairman Conference*

Consideration was given to the recommendation that the Chapter Chairman Conference by a two-day meeting, and that a definite date be decided upon, and it was moved by Director Kuniansky, seconded by Director Jacobs, and carried:

> "That the Chapter Chairman Conference be a two-day meeting, and that it be held on July 17 and 18, 1945."

The expense of the Chapter Chairman Conference was approximated for the two-day meeting in comparison with the meeting held last year, and the geographical distribution of the chapters in regard to allocating the expenses for this annual meeting was discussed. On motion by Director Kuniansky, seconded by Director Wood, it was unanimously carried:

> "That the expense of the Chapter Chairman Conference be borne by the A.F.A."

15. *1945 Annual Meeting*

In view of the feeling that the Chapter Chairman Conference, the annual Board meeting, and the annual meeting of the Association, might well be held this year during the same week, Director Kuniansky moved:

> "That the annual meeting of A.F.A. be held on July 18 at a place designated by the Executive Committee."

Motion seconded by Director Rycroft, and unanimously carried.

16. *Youth Encouragement Committee*

Chairman Walls in reporting on the activities of the Youth Encouragement Committee stated that he had visited three chapters and discussed with them the importance of youth encouragement. He stated that in addition to these chapter discussions, he had talked with General Motors officials who have evidenced much interest in this activity.

17. *Report on Conference with Ordnance Department*

Vice-President Walls reported on the conference that he, President Teetor and Secretary Kennedy were invited to attend at the request of the Ordnance Department, to formulate plans to cooperate with the Ordnance Department through an A.F.A. committee whose services would be available to the research and development department for consultation on matters concerning the foundry industry.

It was suggested that five 5-man committees be appointed, representing the different divisions, with the chairman of each committee forming a general committee of five to work with the Ordnance Department, with one man as liaison to attend general meetings, and this suggestion had the unanimous approval of the Board.

18. *Report of Technical Development Program*

N. F. Hindle, Director of the Technical Development Program, reported quite fully on this subject, outlining the activities and commenting briefly on the progress being made on those already started, together with the plans for future projects, as well as the special service that would be available under this new setup.

Director Wood, Chairman of the Technical Development Advisory Committee, gave his views on the function of the committee, which would be clarified as to aims and policies after their first meeting.

On motion by Director Wagner, seconded by Director Forbes, the report was accepted.

19. *Classification of A.F.A.*

It was the consensus of opinion that the classification of the American Foundrymen's Association should be clarified with the Internal Revenue Department, and that steps should be taken to stress the fact that the A.F.A. is a technical society, and not a trade association. It was suggested that this fact might well be incorporated on A.F.A. stationery and literature.

There being no further business, the meeting was adjourned.

Respectfully submitted,

R. E. KENNEDY,
Secretary.

Summary—Report of Special Subcommittee on Dues

In Session November 14, 1944, Chicago

After lengthy analysis of the dues structure of A.F.A., the Special Subcommitte on Dues has prepared a 19-page report. This report includes the following recommendations for action by the Executive Committee.

1. That dues of Sustaining Members be increased from $50.00 minimum to $100.00 minimum annually.
2. That dues of Company Members be increased from $25.00 to $50.00 annually.

No sliding scale of Company dues—based on (a) number of Affiliates, (b) number of employees, (c) sales, or (d) tonnage capacity—is considered advisable. No limitation on the number of Affiliates per company is recommended. However, it also is recommended:

3. That the chapter refund on dues be increased to a straight 20 per cent.

Respectfully submitted,
F. J. Walls, *Chairman*
I. R. Wagner
W. B. Wallis

Minutes of Special Meeting
Executive Committee of the Board

Palmer House, Chicago, Ill. February 6, 1945

Presiding: A.F.A. President R. J. Teetor
Attendance (for A.F.A.): Vice-President F. J. Walls
Director D. P. Forbes
Director H. S. Simpson
Director W. B. Wallis
Director S. V. Wood
Secretary R. E. Kennedy
Treasurer C. E. Hoyt
T.D.P. Director N. F. Hindle
Bus. Mgr. W. W. Maloney
(For Foundry Equipment Manufacturers Assn.):
President Thos. Kaveny, Jr., Herman Pneumatic Machine Co.
Director M. S. Becker, Whiting Corp.
Director B. C. O'Brien, Roots-Connersville Blower Corp.

This meeting was called by President Teetor in order to clarify with officials of the Foundry Equipment Manufacturers Association (F.E.M.A.) those features of the 1945 "Year 'Round Foundry Congress" having to do with advertising in the AMERICAN FOUNDRYMAN.

It will be recalled that the Board of Directors at the mid-year meeting held January 17, 1945, voted to adopt an emergency program of activities in lieu of the 1945 Convention, so as to provide some other means of bringing to the members those papers and discussions intended for the canceled Detroit Foundry Congress. Accordingly, it was voted unanimously, with 100 per cent of the Board attending, to suspend publication of the quarterly Transactions, to publish this Transactions material in AMERICAN FOUNDRYMAN beginning with the May, 1945, issue, and to replace the Pre-Convention issue of AMERICAN FOUNDRYMAN with advertising in those monthly issues containing Transactions material.

Acceptance of monthly advertising had previously been urged by a number of members and recommended by several previous Board committees on AMERICAN FOUNDRYMAN policy. It was felt that the added revenue from monthly advertising would materially benefit A.F.A. in its ability to perform greater service for the industry. The May, 1945, issue was selected as the first issue for monthly advertising, because it was decided to begin the publication of Transactions material in that issue.

Immediately after the January 17 meeting of the Board, information reached several directors, as well as members of the staff, that the Foundry Equipment Manufacturers Association was strongly opposed to such an advertising program. Accordingly, the February 6 meeting was called as a special meeting of the Executive Committee to meet with directors of F.E.M.A. and discuss the matter thoroughly. The good will and cooperation of F.E.M.A. members, most of whom are members of A.F.A. and previous exhibitors at foundry shows, was felt most desirable for a successful program of advertising.

Invitation to attend was issued to the officers and directors of F.E.M.A. on February 1. It was felt that prompt action was necessary before making an official announcement of the advertising program, hence the short time intervening between the invitation and the meeting. F.E.M.A. Vice-President O. A. Pfaff, American Foundry Equipment Company; Director H. S. Hersey, C. O. Bartlett & Snow Co.; Director R. W. Hisey, Osborn Manufacturing Co.; Director P. J. Potter, Pangborn Corp.; and Director B. L. Simpson, National Engineering Company, expressed regrets at not being able to attend.

A.F.A. President Teetor called the meeting to order at 10 a.m. on February 6, and requested reading of the 1945 program of emergency activities occasioned by cancelation of the Detroit Convention.

F.E.M.A. President Tom Kaveny then asked permission to read a memo from Otto Pfaff to his company's sales promotion manager, A. L. Lenhard, dated January 31, on the subject of this program. Mr. Kaveny stated that this letter expressed in general the objections of F.E.M.A. to the A.F.A. advertising program, and discussion followed.

Dealing with the points involved in Mr. Pfaff's memo, the A.F.A. directors pointed out that A.F.A. is the only technical society today which does not accept advertising in its publications, and, therefore, did not feel that A.F.A. was unduly commercializing its activities.

A memo was read by F.E.M.A. Director Max Becker, from the Whiting Corp. advertising agency, the Fensholt Co., expressing the opinion that the acceptance of advertising should be confined to regular commercial publications. Other F.E.M.A. directors expressed the fear that the new A.F.A. program might unduly commercialize A.F.A. activities.

A.F.A. directors pointed out the value of Transactions material to the industry as being of advantage to any prospective advertiser. Some thought was expressed by F.E.M.A. directors that Transactions material would be of less value to advertisers than might be anticipated by A.F.A. It was pointed out by A.F.A. that the 7,600 members of A.F.A. represented a splendid circulation for any advertiser to reach. It was stated that the AMERICAN FOUNDRYMAN would be sold on its merits as an advertising medium and that its success or failure should depend on merit selling alone.

Some disagreement was expressed as to the possible net income that might be derived by A.F.A. from the advertising program. A.F.A. Director Wood, however, pointed out that the work of A.F.A. over the years has been of material benefit to the entire industry, and that additional revenue expected to be derived through advertising would be returned to the industry many-fold in terms of greater service.

He stated that no compulsion whatever would be placed on any equipment company under this program, but that the wishes of each would be respected in its assessment of the value of AMERICAN FOUNDRYMAN to its own sales program. Mr. Wood pointed out that the subject had been thoroughly considered by the A.F.A. Board over a period of many years and that the resulting increased service to the membership, through the valuable addition of advertising data in the AMERICAN FOUNDRYMAN, was a material factor in the Board's decision of January 17.

President Teetor recalled the splendid support that has always been given A.F.A. activities by the equipment and supply trade, through membership, exhibit participation, contributions to special projects, and the like. He pointed out that the constantly increasing membership of A.F.A. is constantly demanding greater service, and that the program adopted was intended primarily to provide a greater degree of service. He stated that the meeting had been called out of consideration for the members of F.E.M.A. and their interest in the program so that the underlying reasons for the Board action might fully be understood prior to any general announcement.

In the matter of competition with existing publications, the A.F.A. board was of the belief that such competition would be beneficial for the industry, rather than harmful, since it might be expected to result in more and better editorial material on the part of AMERICAN FOUNDRYMAN as well as any other magazine serving the foundry field. The A.F.A. directors felt that such an increased volume of editorial matter could not help but benefit the industry, the equipment and supply companies, and the foundrymen. It was pointed out by the A.F.A. staff that, because of existing paper limitations, only a limited volume of advertising could be accepted in AMERICAN FOUNDRYMAN during 1945, and it was declared that in any event the editorial content of the magazine would be considered first.

The suggestion was made that, if the program was considered from the standpoint of needed additional revenue, A.F.A. should not overlook the possibility of contribution financing. Director Wood expressed the thought that such a method of financing would not enable A.F.A. to plan ahead as it should, since each year's revenue would be contingent upon some unknown factor. He stated that A.F.A., as a technical society for the entire industry, was in a position to stimulate greater foundry progress, if properly financed, and he expressed the belief that the advertising program would be of material assistance to that end.

A.F.A. Director Simpson suggested that the advertising program be deferred until 1946, or at least until after the Annual Board Meeting in July, 1945, and that the intervening months be used to gain the full cooperation of equipment and supply companies with the contemplated program. Other A.F.A. directors expressed the thought that the best way to determine whether such cooperation could be gained or withheld, would be through actual solicitation of advertising from month to month during 1945.

It was pointed out that the present advertising program as adopted in January is authorized only for the eight months, May-December, 1945, inclusive, and that any extension of the program beyond 1945 is contingent on further Board action.

President Teetor stated that announcement of the advertising program would be made as soon as possible after the meeting, and that the A.F.A. Board would be kept advised as to the success of advertising solicitation prior to the May issue. He stated that cancelation of the Detroit Convention had made necessary a drastic change in our publication policies in order to provide continuous service to the members, and that A.F.A. would welcome any suggestions by F.E.M.A. which might lead to a degree of cooperation between the two organizations even greater than has existed for many years.

Following the meeting, the staff was instructed to make the initial announcement of the advertising program as promptly as possible, to begin with the May issue of AMERICAN FOUNDRYMAN, and to respect the expressed decision of any prospective advertiser as to his own participation.

Respectfully submitted,

R. E. KENNEDY,
Secretary.

Minutes of the Executive Committee Meeting

Palmer House, Chicago. April 26-27, 1945

Presiding: President R. J. Teetor

Present: President R. J. Teetor
Vice President F. J. Walls
Directors: W. B. Wallis
I. R. Wagner
L. C. Wilson
S. V. Wood

1. This meeting was called primarily as an executive session for the purpose of giving thorough consideration to the functions of the members of the Staff at the National Office and to consider, especially, recommendations that might properly be made to the Board of Directors at the July meeting relating to the retirement of Treasurer C. E. Hoyt and a reassignment of duties to Secretary Robert E. Kennedy.

2. Ed Hoyt has sought to retire as an active officer of the Association from time to time over a period of several years, but has continued to respond to needs of the Association as they have developed with the broadening of its functions and increases in its membership. The Executive Committee, after very careful deliberation unanimously approved the proposal made by Treasurer Hoyt in this connection and offered the following recommendation to the Board of Directors, to-wit: That C. E. Hoyt be retired as Treasurer on August 1, 1946, at a mutually agreed retirement pay; and further, that any actual services after August 1, 1946, that may be requested by the Association of Mr. Hoyt and which he performs, shall be recognized by suitable compensation in addition to his retirement pay.

3. With full consciousness of the responsibility of the Executive Committee and the Board of Directors as to the services which should properly be required from Secretary Robert E. Kennedy, in the light of health warning signals which have appeared during the last year and a half, it was the unanimous conviction of the Executive Committee that in order to preserve to the Association for the longest period possible, the inspiration and to a limited extent the services of Secretary Kennedy he should be immediately relieved of all duties as the chief executive of the Association.

It was the further unanimous recommendation of the Executive Committee and with the complete approval of Robert E. Kennedy that he be retired as Secretary effective August 1, 1945, at retirement pay of a mutually agreed amount per annum.

It was further recommended by unanimous action of the Committee that in recognition of his long and unselfish service to the Association in the capacity of Technical Secretary and of Secretary that Robert E. Kennedy be accorded the title of "Secretary Emeritus" of the American Foundrymen's Association, and that his services be used at such times and to such extent as convenient to him in carrying out any special projects for the good of the Association and in which he may have interest, such projects to be carried out under the direction of the then Secretary of the Association. It is to be understood that in the acceptance of the above provisions if awarded by the Board of Directors, Secretary Robert E. Kennedy was to consider himself under no obligation at any time to perform any function but was to be made welcome as "Secretary Emeritus" at his convenience.

4. It was the unanimous recommendation of the Committee that Norman F. Hindle be retained as Director of the Technical Development Program at such salary as may be approved by the Board.

5. It was the unanimous recommendation of the Committee that Business Manager William W. Maloney be designated to fill the vacancy of Secretary at August 1, 1945, at an annual salary of a mutually agreed amount.

6. It was recognized that the form in which these unanimous recommendations of the Executive Committee were presented may well be subject to criticism, but the gist of the Committee's deliberations were placed before the Board.

Such comments as have been made in regard to the services of Ed Hoyt and Bob Kennedy could not possibly be considered as an adequate recognition of what they have done for the Association. Proper formulation of a recognition of that character will have to be left to a later moment and to better recorders. But the Committee did find it quite impossible to set forth their deliberations with the usual brevity of form without interjecting something of the sentiments expressed during the meeting and the hope for many years more of useful contacts with A.F.A. by these two revered and loved executives.

Respectfully submitted,

R. J. Teetor, *President*
F. J. Walls
W. B. Wallis
I. R. Wagner
L. C. Wilson
S. V. Wood

Minutes of the Executive Committee Meeting

Palmer House, Chicago, Ill. June 15, 1945

1. Present: President R. J. Teetor
Vice President F. J. Walls
Directors: W. B. Wallis
I. R. Wagner
L. C. Wilson
Secretary R. E. Kennedy
Treasurer C. E. Hoyt
Technical Development Director N. F. Hindle
Business Manager W. W. Maloney
Assistant Treasurer J. Reininga
Absent: Director S. V. Wood

2. *Reading of Minutes*

The meeting was called to order by President Teetor and at his suggestion the reading of the minutes of the January 16, 1945, meeting was dispensed with, having been submitted by mail and approved.

3. *Discussion of* AMERICAN FOUNDRYMAN *Advertising Policy*

Business Manager Maloney reported on results to date from the solicitation of advertising on a monthly basis. He stated that, based on W.P.B. paper permits as of November, 1944, it was estimated that a total of 320 pages of advertising could be accepted in AMERICAN FOUNDRYMAN for the eight months, May-December inclusive, 1945. As of July 1, a total of 310 advertising pages had been reserved or run in the monthly magazine.

It was pointed out that Board authority to accept advertising in monthly issues covers only 1945, and no commitments beyond December, 1945, have been made. Discussion followed as to advisability of continuing the Program.

On motion by Director Wilson, seconded by Director Wagner, it was unanimously voted:

> "That the Executive Committee recommends, on the basis of the figures presented, continuing the acceptance of advertising in the AMERICAN FOUNDRYMAN, and that the Quarterly TRANSACTIONS be discontinued as now."

4. *Report of Committee on Chapter Contacts*

Chairman Wagner briefly reported on the Chapter Contacts Committee and stated that every chapter had been visited during the year.

5. *Membership Eligibility*

The question of submitting new membership applications to the chapter membership committees to determine eligibility was discussed, and it was decided that this should be given further consideration at the Chapter Chairman Conference.

6. *Chapter Organization Possibilities*

President Teetor reviewed past policy followed in regard organization of new chapters with the thought in mind that some definite plan should be established in adding to the present number of chapters. It was suggested that the sub-group idea should be encouraged and that a systematic plan should be devised in organizing these special groups, with due consideration for neighboring chapters.

7. *1946 Convention and Exhibits*

Business Manager Maloney commented on prospects for a convention in 1946, as well as an International Foundry Congress in conjunction with the 50th Anniversary meeting, and after a brief discussion, Vice-President Walls moved:

> "That a recommendation be made to the Board to proceed with plans for the 1946 International Foundry Congress."

Motion seconded by Director Wallis and carried.

8. *Report on Solicitation Results for the Technical Development Program*

Treasurer Hoyt reported briefly on direct-by-mail efforts in soliciting contributions for support of the Technical Development Program.

9. *Report on Activities of Technical Development Program*

Mr. Hindle reported on activities of the Technical Development Program, and in the absence of S. V. Wood, Chairman of the Technical Development Program Advisory Committee, raised the question of establishing a clearer policy in regard to research projects acceptable for TDP sponsorship. The Executive Committee emphasized the undesirability of conducting solicitations of funds for projects of specific interest, rather than of general interest, in the name of A.F.A., but agreed that the TDP Advisory Committee should be held responsible for acceptance of projects submitted for TDP sponsorship.

The suggestion was made that the TDP Advisory Committee present a resolution to the Board of Directors, for their approval, reflecting the Committee's views on a proper basis for acceptance or rejection of projects offered.

10. *Treasurer's Report*

Treasurer Hoyt presented the Budget Reports and Receipts and Disbursement Statements of the regular activities and Technical Development Program for period ending May 31, 1945. The advisability of investing some of the unused assets in treasury notes was discussed, and it was moved by Vice-President Walls, seconded by Director Wallis:

> "That $40,000 of the General Fund and $5,000 of the Cupola Research Fund be invested in 1½% Treasury Notes."

Motion unanimously carried.

11. *Membership Report*

Chairman Walls gave a brief report on the status of membership, and commented favorably on the steady increase in members. He suggested that particular attention should be given to any cancellations, especially in regard to Sustaining memberships.

On motion, seconded, and carried, the report was approved.

12. *1945 Annual Business Meeting*

Secretary Kennedy outlined plans for the 1945 Annual Business Meeting, to be held the evening of Wednesday, July 18th. He announced that the annual dinner would be held in conjunction with the Chapter Chairman Conference and Board of Directors meeting, and that all members in the Chicago Chapter were being invited to attend.

13. *Report of Ordnance Department Contact Committee*

Secretary Kennedy reported on the activities of the Ord-

nance Contact Committee, stating that they had one inquiry from the Frankford Arsenal, which had been very ably handled by the Non-Ferrous Section of the Committee.

14. *Report on Reclassification of Treasury Department Ruling*

Mr. Hoyt reported on the classification of the Association by the Internal Revenue Department and stated that this should be changed from Section 101(6) to Section 101(7) in keeping with the fundamental purposes of A.F.A. After some discussion, Mr. Wilson moved:

> "That authority be given to employ the necessary counsel to advance the matter of reclassification with the Internal Revenue Department."

Motion seconded by Director Wagner and carried.

15. *Policy on Future Distribution of AFA Publications to Members*

The matter of free publications to members was discussed, resulting in a motion by Director Wallis:

> "That the policy of not giving free books to members be continued for another year."

Motion seconded by Director Wagner and carried.

There being no further business, the meeting was adjourned.

Respectfully submitted,
R. E. KENNEDY,
Secretary.

Minutes of Annual Meeting 1944-45 Board of Directors

Palmer House, Chicago, Ill. July 18, 1945

1. Presiding: R. J. Teetor, President
Present: President R. J. Teetor
Vice-President F. J. Walls
Directors (1944-45):
J. E. Crown
D. P. Forbes
R. M. Jacobs
Max Kuniansky
S. D. Russell
R. T. Rycroft
H. S. Simpson
Joseph Sully
I. R. Wagner
W. B. Wallis
L. C. Wilson
S. V. Wood
W. L. Woody
Absent: Directors: F. J. Dost
Harry Reitinger
J. H. Smith
Also Present: Directors (newly elected):
G. K. Dreher
E. W. Horlebein
H. H. Judson
F. M. Wittlinger
Staff: Secretary R. E. Kennedy
Treasurer C. E. Hoyt
Technical Development Director N. F. Hindle
Business Manager W. W. Maloney
Assistant Treasurer J. Reininga

2. Minutes of the following meetings were read and approved.
Board of Directors' meeting January 17, 1945
Special Executive Committee meeting February 6, 1945
Executive Committee meeting June 15, 1945
Reading of the Minutes of the Executive Committee meeting held April 26 - 27, 1945, was temporarily deferred.

3. *Financial Report*

The auditor's report on A.F.A. finances for the fiscal year ending June 30, 1945, was presented by Treasurer C. E. Hoyt, in the form of Balance Sheet and Statement of Income and Expenses for both the General Funds and the Technical Development Program.

Commenting on the comparative figures for recent years, the Directors stressed the desirability of operating the Association on a self-sustaining basis during non-exhibit years as well as exhibit years, without the necessity of transferring funds from exhibit year surpluses for operations during non-exhibit years. It was felt desirable that any profits from exhibits should go into surpluses or reserves, rather than be used for operating expenses.

Director L. C. Wilson, as Chairman of the Finance Committee, stated that it should be possible to budget for 1945-46 without appropriating from 1944-45 income, providing there is no drastic change in the present financial picture. Treasurer Hoyt stated that budget calculations for 1945-46 were based partly on continued success in the sale of advertising space in AMERICAN FOUNDRYMAN, in the light of space sales and reservations thus far for the calendar year 1945.

On motion by Director Woody, seconded by Director Rycroft, the Treasurer's report was accepted.

4. AMERICAN FOUNDRYMAN *Advertising*

Resolutions received from the Foundry Equipment Manufacturers' Association and the Foundry Supply Manufacturers' Association were read, both requesting the A.F.A. Board to reconsider its action on acceptance of monthly advertising in AMERICAN FOUNDRYMAN. Reference was made to the Minutes of the Special Executive Committee meeting held February 6 with Directors of F.E.M.A., and the opinions expressed at that time and since by members of F.E.M.A. regarding advertising.

Discussion by the Directors brought out a number of points pertaining to reception by A.F.A. members, service performed by the magazine, and advertising revenues and reservations to date. Action taken by the Board was embodied in a motion by Director Woody that President Teetor communicate to the F.E.M.A. and F.S.M.A., the A.F.A. Board's reasons why its previous action regarding advertising for 1945 could not be reconsidered. This motion was seconded by Director Wilson and passed.

No action was taken on the question of advertising in AMERICAN FOUNDRYMAN beyond 1945, this question being deferred to the new Board.

5. *Staff Re-organization*

Minutes of the Executive Committee meeting held April 26-27, 1945, were read and discussed in Executive session. As a result, and in consideration of the necessity for progressive action by the new Board regarding staff organization, the following motion was moved, seconded and carried:

> That the 1944-45 Board of Directors approves and recommends to the 1945-46 Board for adoption, the Executive Committee's recommendations of April 26-27 as modified by the old Board.

6. *Membership Report*

Vice-President F. J. Walls, as Chairman of the National Membership Committee, presented a summary of memberships as of June 30, 1945, pointing out the continued rapid growth of the Association, with an increase of 1,200 members during the past year, to a new high of 7,815 total. Vice-President Walls particularly praised the work of the Chapter Membership Committees in accomplishing this remarkable gain.

A report on the receipt of dues since July 1, 1945, was given by Assistant Treasurer Jennie Reininga, indicating that the new dues structure effective July 1 was being well received by the membership.

7. *Secretary's Report*

Secretary R. E. Kennedy submitted a mimeograph report covering the duties of his office during the past year. He

pointed out that four new chapters had been formed during 1944-45, making the total number of chapters 31, with 93.4 per cent of all members holding chapter affiliation. The report included a review of Technical Committee work, the formation of the Technical Development Program and inauguration of the AMERICAN FOUNDRYMAN in new and approved form.

8. *Technical Development Program Report*

N. F. Hindle, Director of T.D.P., presented an extensive report covering the first year of T.D.P. operation, analyzing its publication, research, library and educational activities.

9. *Chapter Contacts Committee Report*

Director I. R. Wagner, as Chairman of the Chapter Contacts Committee, reported briefly, with special reference to the holding of National Officers' Nights by the chapters during 1944-45, and a first annual Chapter Chairman Conference held in August, 1944. He stated that a great deal of good had been accomplished in establishing closer relations and better understanding between the chapters and the National Officers and Directors and Headquarters Staff.

10. *Report of* AMERICAN FOUNDRYMAN *Policy Committee*

Director D. P. Forbes, as Chairman of the AMERICAN FOUNDRYMAN Policy Committee, presented a brief report covering the improvement in the magazine, its broader and more extensive editorial content and the addition of advertising pages effective with the May, 1945, issue.

11. *New Chapter Possibilities*

Secretary R. E. Kennedy reported on possibilities for establishing new chapters, stating that interest has been shown in setting up new foundry groups in Western Massachusetts, Vancouver, B.C., and Peoria, Illinois.

12. *Technical Development Program Funds*

Treasurer C. E. Hoyt reported on results obtained in the solicitation of funds for the Technical Development Program. He stated that it was planned to continue such solicitation for the remainder of 1945, with some additional concentration devoted to the balance of 1945, with some additional concentration devoted to the latter four months of the year.

13. *Resolutions on Henry D. Miles*

President Teetor called to the attention of the Board, with deepest regrets, the recent death of Past President H. D. Miles. Director Simpson moved, Director Crown seconded and the Directors voted unanimously to instruct C. E. Hoyt as the Alumni Secretary to prepare a suitable resolution for spreading on the Minutes of the Association and for transmission to the bereaved family of Henry Miles, the Association's deepest sympathy and sorrow.

14. *Endowment Fund*

President Teetor called attention to the splendid work performed for the Association by Director and Past President H. S. Simpson and announced that Director Simpson had offered to endow in the Association a fund which might possibly be utilized for the founding of an A.F.A. Gold Medal Award or similar memorial to the memory of Peter L. Simpson, details to be worked out under the jurisdiction of the new Board.

15. *President's Recommendations*

As the retiring President, President Teetor submitted to the new Board his recommendations pertaining to conduct of A.F.A. affairs during the coming year. He paid special tribute to the 1944-45 Executive Committee, consisting of Messrs. Walls, Wood, Wallis, Wilson and Wagner, and their willingness to give valuable time for the several meetings held during the past year, and the constructive work they performed on every occasion.

President Teetor then announced the retirement of Directors J. E. Crown, H. S. Simpson, I. R. Wagner and W. L. Woody and paid every man tribute for his work on the Board during the past three years.

There being no further business, President Teetor adjourned the meeting.

Respectfully submitted,
R. E. KENNEDY,
Secretary.

AMERICAN FOUNDRYMEN'S ASSOCIATION

Third Foundation Lecture—1945

Solidification of Metals

By Harry A. Schwartz*,

Cleveland, Ohio

THERE should be no hesitation in talking to foundrymen on the subject "Solidification of Metals." We live by pouring liquid metal into molds and selling the solidified object to a customer. Like it or not, the foundryman must be concerned with the question of producing a frozen piece of metal having a desired form, free from injurious voids, and of a micro-structure and macro-structure consistent with certain desired physical properties. Furthermore, for competitive reasons, it is desirable to accomplish this end with a minimum expenditure, whether of money or labor.

We may disregard any question of what constitutes reasonable conformity to perfection in these matters, and confine our attention to the principles underlying the attainment of any desired results. These will be found to fall into three classes: (1) principles underlying the conduction of heat through materials; (2) physical properties of the metals and mold refractories with which we have to deal; and (3) laws underlying the crystallization of solids from the liquid state. All these have been extensively studied, some of them over many years. Despite this there are many gaps in our knowledge and much work remains to be done.

Heat Transfer

The fundamental relation describing the conduction of heat through a solid body is called "Fourier's law," and states that the quantity of heat transferred across a unit area within a body in a unit time is proportional to the thermal gradient perpendicular to this area. The constant of proportionality which gives the actual quantity of heat transferred per square centimeter in one second if the gradient be 1° centigrade per centimeter is represented by the symbol k and is called "thermal conductivity." It differs from substance to substance and changes with temperature for any given substance.

The study of heat transfer falls at once into two classes. The first, known as the steady state, represents the transfer of heat through a solid within which there is a temperature gradient but no point in which changes temperature. The transfer of heat through a surface condenser from a hot steel surface, in contact with steam, to a cold surface of the same steel, in contact with water, is an illustration of such heat transfer. Its mathematical treatment, whether the flow of heat be linear, radial in a single plane, or radial in three dimensional space, is quite simple. The conduction of heat into or through a body which itself changes temperature in the process, as for example the cooling of a hot object when immersed in a quenching bath, or the heating of the sand in a mold filled with hot metal, is mathematically far more complicated. The foundation for the study of such problems was laid in 1822 by Napoleon's mathematician, Fourier, whose great contribution was a method of attack for evaluating the differential equations which could be set up in the light of the law bearing his name.

The problems which can be adequately dealt with by mathematical means are, however, somewhat limited. Rigidly speaking, it is possible to deal only with certain mathematically simple cases. The principal ones are the transfer of heat into or out of the so-called semi-infinite solid which is considered to be an indefinitely large mass having one face accessible to heat input or output, in an indefinitely large flat plate, in an indefinitely long cylindrical rod, and in a sphere. The transfer of heat between two bodies in contact with each other can be handled only if both bodies are of the same material or if the two materials have identical thermal properties, which would not happen unless they were identical. Analysis of the Fourier type becomes very difficult if the specific heat of the substance changes materially with temperature, as it does for most substances, and becomes practically impossible if the heat content is not a continuous function of temperature; that is, if the substance changes from solid to liquid, absorbing heat without change of temperature, or vice versa. His analysis does not apply to the transfer of heat through fluids, which is largely accomplished by convection currents, because Fourier's analysis is based only on the transfer of heat by conduction.

The thermal properties of substances can be studied with sufficient precision for heat transfer calculations without overwhelming difficulty, except at high temperatures where the experimentation meets with practical handicaps. We are concerned primarily with the density, the specific heat, and the thermal conductivity, all as functions of temperature, and with latent heats of fusion and transformation, where these are involved. Physical chemistry gives us some guide to generalization and those who have concerned themselves with the structure of matter are adding to our fundamental knowledge of these subjects. Since there are vast numbers of materials, we necessarily lack definite data about many. It is natural, however, that the thermal properties have been studied most frequently for the most common and industrially most important substances, so that this lack is not too serious. The experimentor can inform us on the changes in thermal properties with temperature for this or that substance, but this does not necessarily help us much in the applications we wish to make.

When either pure metals or eutetic alloys of several metals freeze, the composition of the solid is the same

*Manager of Research, National Malleable & Steel Castings Co.

as that of the liquid. In all other cases freezing is "selective." That is, the composition of the solid material differs from that of the liquid material. Also, the composition of both the solid and the liquid phases changes with temperature during the process of freezing. In selective freezing the substance does not change its state sharply at a single temperature, as do the pure metals and the eutectic alloys, but freezing takes place over a temperature interval. It is very simple to calculate the relative amounts of solid and liquid which should exist in equilibrium with one another at any given temperature within the freezing range if we knew the composition of the two phases. In many cases these compositions can be calculated from very fundamental thermodynamic constants of the substance. If, however, cooling takes place too rapidly, equilibrium will not be attained, and the results will not conform with prediction. The rate of formation of the solid metal will be influenced by the number of nuclei or centers of crystallization which can form under the temperature conditions accompanying a given cooling rate, and upon the rate at which solid crystals can grow. All who have observed the crystallization of "rock candy" from saturated sugar solutions will realize that, generally speaking, crystals do not form at indefinitely rapid rates, but that their growth is a process involving time.

Ultimate Desire to Obtain Solid Castings

What the foundryman wishes ultimately to attain is a control of solidification in such a way that the voids, be they inter-dendritic and on a microscopic scale, or large shrinks, can be filled up by a supply of new metal so as to produce a solid casting. The fundamental principle is that solidification shall begin at those parts furthest removed from the last remaining source of liquid, and shall progressively approach this source. In foundry terms, freezing should take place toward the feeder. This process is generally known as progressive solidification and has been dealt with by many writers, among whom Briggs and Gezelius should be particularly mentioned. When attained, progressive or directional solidification may be inconsistent with the prevention of cracks or tears.

Unfortunately we can not comply literally with the foundryman's request for a rigid treatment of the subject from the viewpoint which is of practical importance to him, but we can play the role of interpreter, explaining the scientific application which must be considered in securing the ends he desires.

A distinguished physician once said that unfortunately no patient ever presented the exact clinical picture described in the text books as characteristic of a given disease. Unfortunately this is true also with regard to castings. None of them ever comply with all the requirements necessary to permit of rigid theoretical discussion. One is, therefore forced to deal with simplifying approximations, which in effect provide a simpler analogy of a problem near enough to the facts so that the conclusions will be applicable within the none too rigid requirements of the foundry. The greatest opportunity for research in this field perhaps lies in a study of how nearly such simplifying assumptions will reproduce the facts, and what simplifying assumptions are warranted. Some progress has already been made in this field. There are several instances in which one can be rather sure that the error of calculation is on the safe side. Then one may be reasonably confident of attaining this purpose, although it may be that the means are more drastic than necessary. The most comprehensible way in which one can interpret for the foundry technician the scientific basis of his art, is probably in the form of a more detailed and illustrated discussion of the three fields already referred to, accompanied by examples illustrating these principles. This is the purpose of the remainder of your speaker's paper.

Solidification of Pure Metals

The logical beginning for any discussion of solidification is consideration of how substances freeze. To the scientist this means a study of equilibrium conditions between two phases (solid and liquid). the foundation for these considerations was laid in the late 70's of the last century by that transcendent genius, Josiah Willard Gibbs, at Yale. Gibbs originated a concept now called "free energy." The free energy of a substance may be thought of as the amount of useful mechanical work which its heat content above the absolute zero could be made to perform. The free energy is not identical with the heat energy content because of the existence of entropy, about which we need not puzzle our minds here. The foundryman need only remember that the free energy of a substance (per gram molecule) is a fixed and specific thing, calculable for any temperature and pressure. As a first approximation, solid and liquid metals do not change much in free energy with changes in pressure, but change greatly in free energy with temperature.

It is among the most fundamental of scientific facts that if a mixture of components in given amounts can be imagined to exist in any one of several states, then the system will spontaneously approach that state in which the free energy content is least. Unlike most human beings, the system wishes to do all the useful mechanical work possible, rather than the least amount. Consideration may well be limited to what happens at atmospheric pressure and the phrase "at atmospheric pressure" will not be needlessly and tediously repeated. If and when we need to consider other measures, that fact will be noted.

Now, what has all this to do with the freezing of metals? Consider Fig. 1. In that figure we have two rather long curved lines representing the free energy content of some unnamed substance in the liquid and solid states, expressed as a function of temperature. At low temperatures the free energy of the liquid state is higher than that of the solid state and the system will tend toward the state of lowest free energy; that is, the substance will solidify. At a higher temperature the reverse is true and the substance will tend to become a homogeneous liquid. At the intersection of the two lines neither substance has the higher free energy, and at that temperature the substance can exist as a mixture of solid and liquid without either trying to go over into the other. The temperature at which this intersection takes place is then the melting point. So far all that has been said may be looked upon as a needlessly complex way of stating the very simple fact that a pure substance has

a sharp melting point. This simple statement, however, does not suffice for our consideration. For practical reasons we must take cognizance of the fact that the melting point of substances, when very finely divided, is different from that usually determined.

For this we require the following explanation, which, though it may appear abstruse, will presently be found to have much to do with the grain size of a frozen metal. When a particle of solid is immersed in a liquid, the pull upon an atom in the surface of the particle is not symmetrical. The atoms inside of the solid will generally pull an atom in the surface inward more strongly than the neighboring atoms in the liquid pull it outward. The result is that substances wish to decrease the ratio of their surface to their volume when immersed in other substances. This they can do by assuming more and more nearly spherical shapes or by the coagulation of many particles into one. The behavior of spilled mercury illustrates both principles. Here the mercury is, of course, immersed in air. If the experiment were made in vacuum, the phenomenon would be even accentuated, for there would then be no outward pull. In any event we can add to the free energy of the solid substance in Fig. 1, an additional amount representing the surface energy. This amount varies with the sizes of the particles, being large when the particle is small, and small when the particle is large. Quantitatively the free energy varies inversely as the cube root of the particles' mass. If our line for the free energy of the solid is representative of individually large particles, the short dotted curves of Fig. 1 will represent the addition made by free surface energy for rather small particles. The entire figure is schematic only. The increase in surface energy, ΔF, is

$$\Delta F = \frac{2\sigma v}{r}$$

when σ is the surface energy (cal. per square cm.), v is the molal volume, and r the radius of the particles. We now observe that with decreasing particle sizes, the melting point goes in the direction of lower temperatures. Let us consider now that the temperature is somewhat to the left of the intersection of the two principle lines in Fig. 1. The

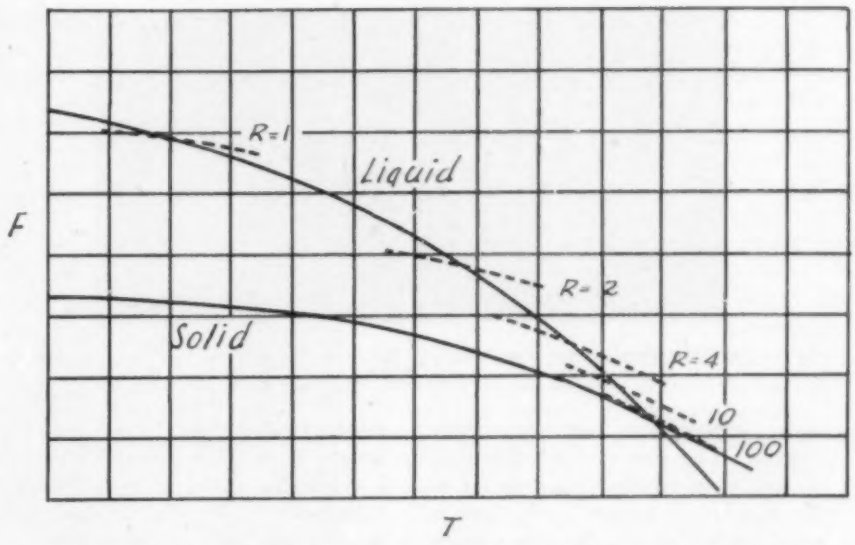


Fig. 1—Schematic. Free Energy Relations Explaining Change of Freezing Point with Particle Sizes.

atoms in the liquid metal are in constant motion. Frequently, as the result of chance, two atoms will be at the right distance required for the growth of a crystal. Less frequently three atoms will be at the right distances and directions to form part of the crystal, and this will be less and less likely the more atoms are expected by accident to reach the positions required to represent a solid crystal. Nevertheless

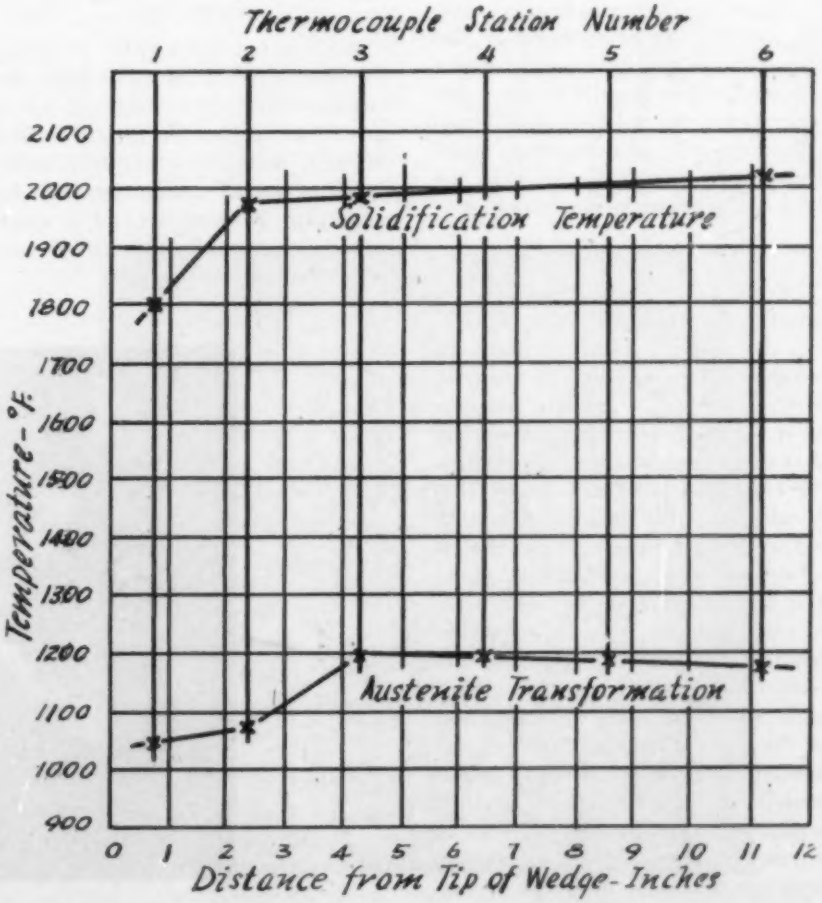


Fig. 2—Depression of Freezing Point in Thin, Hence Quickly Cooled Sections. (Schneidewind and d'Amico.)

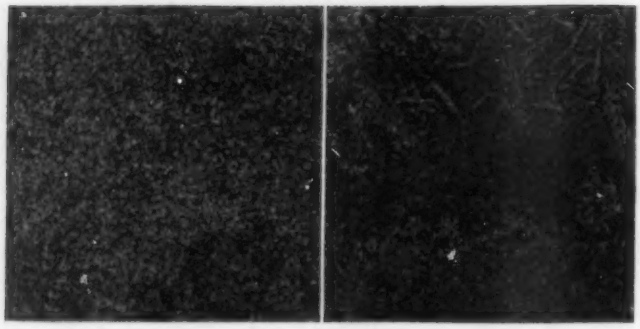


Fig. 3—(a) Steel Frozen from Many Nuclei. (b) Steel Frozen from Few Nuclei. Approximately Full Size.

such aggregations are constantly forming. The size of these potential crystals is, of course, proportional to the number of atoms. If this size is great enough so that the free energy of a particle of this size is less than of the liquid, the nucleus will continue to grow. If the particle is smaller, so that its free energy is greater than that of the liquid, it will re-melt and disappear. The quantitative treatment of the subject would be complex, but it will be plain that as the temperature falls, the sizes of the aggregations which must form by accident, if they are to continue to live as solids, becomes less and less. We have, therefore, the phenomenon that when a substance is cooled rather rapidly to some distance below the melting point, crystallization will proceed from more and more surviving nuclei the greater the degree of supercooling.

Supercooling

"But," you will say, "how can you possibly supercool a liquid metal below its melting point without its solidifying?" The answer is two-fold. First, that it can be done in practice, as is shown in Fig. 2, and second, that there is a good scientific reason. All crystalline substances have what is called a linear velocity of crystallization. This represents the rate at which the substance can take atoms and build them, layer by layer, upon its own surface. It varies somewhat from substance to substance, but within any range of supercooling with which we may be concerned, it does not vary significantly with temperature. If we consider the growth of a single crystal from a liquid, it can only give off heat at a rate proportional to its surface area multiplied by its linear crystallization velocity. The constant of proportionality is, of course, the latent heat of fusion (per unit volume). It may be, therefore, that in a given experimental set-up, heat is withdrawn from the liquid faster than it can be liberated by the growth of the existing crystals, in which case the liquid would fall in temperature and supercooling would take place. Observe that if but few crystals are growing in a given volume of liquid, the heat given off by crystallization per unit time will be less than if many crystals are growing. Consequently supercooling is favored by the elimination of nuclei.

Grain Size

Perhaps an apology is necessary for assuming in the preceding discussion that single crystals of metal grow from a nucleus. Single crystals of many metals can be grown under very unusual conditions, but the aggregate growing around a single nucleus is actually a mass of very small crystals (crystallites).

The significance of nuclear number to grain sizes is well illustrated in Fig. 3. Both (a) and (b) are intermediate carbon steel of essentially the same composition. The areas shown are from near the middle of a fairly large ring of fairly large cross-sectional area. In Fig. 3 (a), the freezing was allowed to go on with but little outside interference. The metal cooled slowly; many nuclei formed and the bulk of the illustration consists of a mass of rather small crystal aggregates. In Fig. 3 (b), the early forming nuclei were removed from the liquid by centrifugal force. The mass then cooled without many centers of crystallization, and the illustration shows the small crystallites accumulated in the bottom where they have settled under centrifugal force, and the remaining liquid frozen in very large dendrites, starting from very few centers of crystallization.

Growth of Crystals

The actual manner of growth of a crystalline mass from liquid metal is of more than passing interest. Fig. 4 shows a mass of crystals of nearly pure magnesium, which have been deposited from magnesium vapor at low pressure. The great perfection of the individual crystals and their arrangement into branching assemblages is both interesting and beautiful.

In Fig. 5 we see the habit of growth of extremely pure bismuth when freezing. The original crystal-

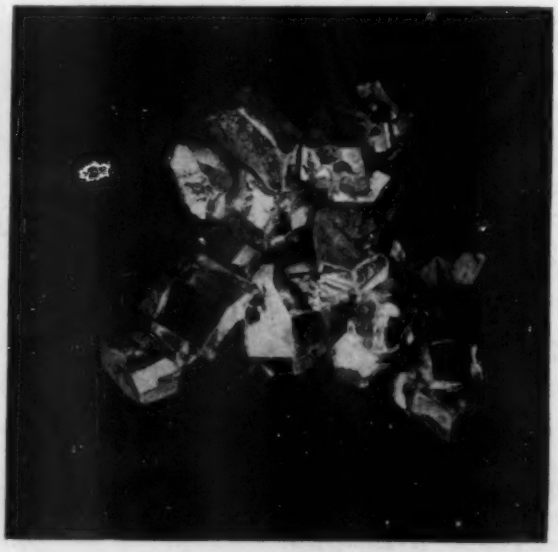


Fig. 4—Crystals of Pure Magnesium Condensed at Low Pressure from Vapor. (Courtesy of K. H. Donaldson.)

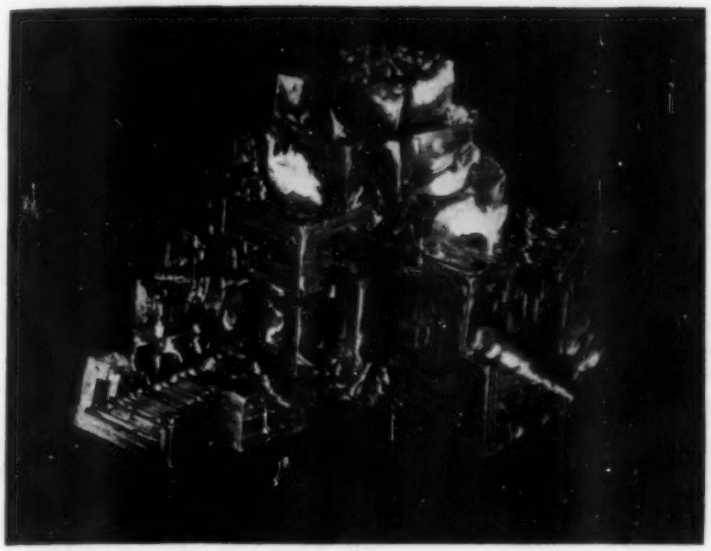


Fig. 5—Eumorphic Crystals of Pure Bismuth. (Courtesy of K. H. Donaldson.)

lites have placed themselves with their diagonals perpendicular with the surface from which heat is removed, and the aggregate has then grown by the deposit of additional crystallites in the direction of the diagonal planes of these cubes. In some cases of selective freezing, particularly, the growth of the solid takes place in a dendritic pattern. A rod-like assemblage of crystalllites grows in the direction of one axis of an octahedron. Branches grow from this stem parallel to the two other octahedral axes and from each of these branches, twigs grow parallel to the two axes at right angles to the branch. Crystallites of this type are sometimes found in the shrinkage cavities of large steel ingot heads. One found many years ago by the Russian, Tchernoff, has been photographed and reproduced in many standard texts. The form of these dendrites is well shown in the low power micrograph reproduced as Fig. 6. The form in which metals are deposited in freezing from the liquid is considerably dependent upon the temperature gradient where the metal is crystallizing, and hence upon cooling rate. If, for example, heat is extracted rather rapidly, so that the remaining liquid metal is appreciably hotter than the freezing point, then the first nuclei will form at or near the mold surface. As the metal cools inward, pseudo crystals will grow inward in a columnar form, all of the heat taken from the surface being supplied by the freezing of liquid at the ends of these columns. The interior of the metallic mass remains too hot for any new nuclei to form inside and grow into an equi-axed pattern. This state of affairs is well illustrated by the freezing of zinc in iron molds, which, on fracture, habitually shows the columnar structure shown in Fig. 7. This condition is evidently further favored if the conductivity of the solid metal is much greater than that of the liquid, for then the temperature at the end of a columnar crystal will be below that of the liquid on each side of it.

The question of how crystals grow when metal freezes in a mold is of more than academic interest. If the assumption could be made that the freezing metal was deposited as a layer of uniform thickness against a mold wall, the problem would be in its simplest form from the foundryman's viewpoint. He would then know precisely to what extent the flow of metal through the partially frozen casting was obstructed when a given degree of solidification has taken place. If the metal freezes by the growth of dendrites at right angles to the mold wall, the problem is far more complicated. In that case we have no sharp plane of demarcation between the liquid and the solid, but a zone in which solid tree-like growths have extended into the still molten material. These growths make the distance to which solid material extends from the wall decidely greater than it would have been had the metal been deposited as a solid layer, and furthermore they obstruct the flow of liquid metal through them, just as undergrowth on the banks of a stream in flood retard the flow of water. Their presence makes the properties of viscosity and surface tension of importance in considering the ability of liquid metal to feed porous areas by flowing into them when they are filled with a sponge-like growth of den-

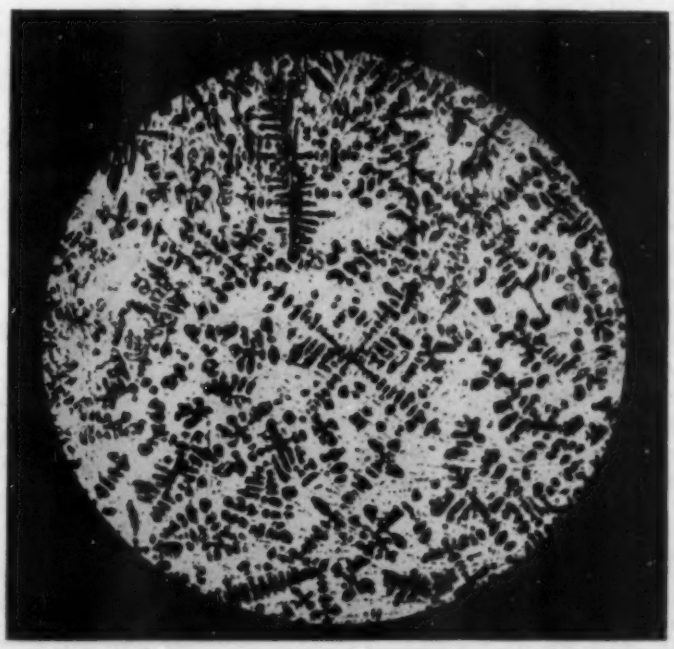
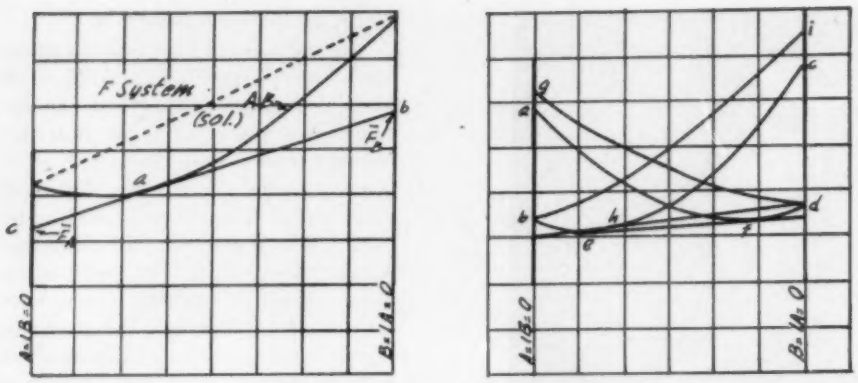


Fig. 6—Dendritic Freezing Pattern in Unidentified Iron Alloy. × 50. (Payne in Author's Laboratory.)



Left Fig. 8—Schematic Diagram Illustrating Partial Molal Free Energies of Components of a Solution. F_A and F_B are the Partial Molal Free Energies of Components A and B in a Solution of Concentration A. Right—Fig. 9—Free Energy Relations of Two Solutions on Equilibrium. The Partial Molal Free Energies of A and B Are Each the Same at Points e and f: Hence Liquids of These Concentrations Are in Equilibrium. At h the Partial Molal Free Energy of B Is That of the Pure Substance and the Liquid Is in Equilibrium with the Pure Component.

dritic axes.

Solidification of Complex Alloys

We have so far considered the solidification of a pure substance, where of necessity the composition of the solid and liquid is the same. This is a very exceptional case in actual practice, for few commercial metals are not alloys of two or more elements. In these cases the liquid always contains all the elements present and the solid usually contains more than one. Such substances do not have a sharp freezing point, but freeze over a range of temperature. Within this temperature range they are partly solid and partly liquid, and we will now direct our attention briefly to the relative compositions and quantities of the liquid and solid phases.

Here we may turn for a starting point again to the principles arising out of Gibbs' pioneer work on heterogeneous equilibrium. At a given temperature we can draw a free energy curve, such as that in Fig. 8, for a solid solution or a liquid solution, showing the relation between free energy and concentration, if solutions exist. Of necessity, these curves will be concave upward. If they were not, then a mixture of the two substances would have a lower free energy than a solution of one in another, and by the principle already enunciated, the system would assume the state of lowest free energy and become a mixture of two pure substances. This might be two layers of liquid metal or a solid substance in which the two components were present as two separate pure phases, depending upon temperature. We would know which system should be expected by observing whether one of the free energy curves is entirely below the other or not. If either is entirely below the other, then the physical state to which it refers (solid or liquid) is the state in which the system finds itself.

In the temperature range of partial solidification we will have two curves intersecting one another, such as are shown in Fig. 9. We require knowledge of what compositions of solid and liquid will be in equilibrium with one another. If at any point on either curve we draw a tangent line and extend it in both directions until it intersects the vertical boundaries of the diagram, then at that particular concentration the solution behaves as though it were a mixture of the two components, having free energies called "partial molal free energies," corresponding to the intersection of the tangent lines with the two vertical boundaries. If the two solutions are to be in equilibrium, then no change of free energy must occur if we take a very small amount of either component out of either phase and introduce it into the other. This means that the two solutions in equilibrium have such compositions that the partial molal free energies of either component are the same, irrespective of which solution is under consideration. Graphically, this is easily determined by drawing a line tangent to both curves. The compositions in equilibrium with each other are then those corresponding to the points of tangency. These points are different for every different temperature.

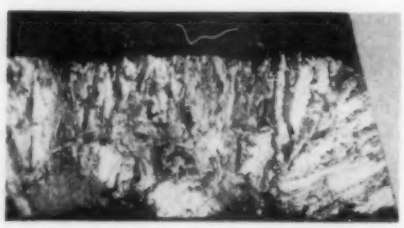


Fig. 7—Columnar Structure of Chill Cast Zinc. (Halpern in the Author's Laboratory.)

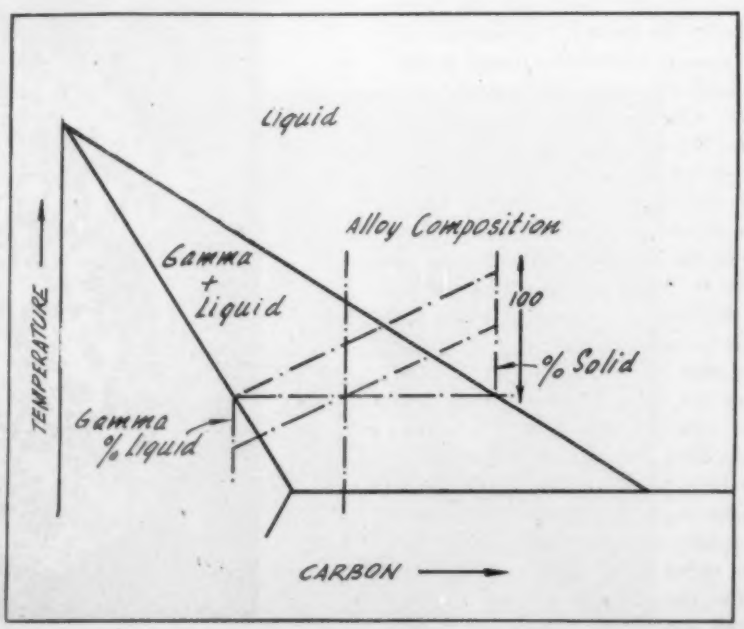


Fig. 10—Partially Solidified Region of the Iron Carbon Equilibrium Diagram, Showing Composition and Relative Amounts of Two Phases in Equilibrium at a Given Temperature in an Alloy of Given Carbon Content.

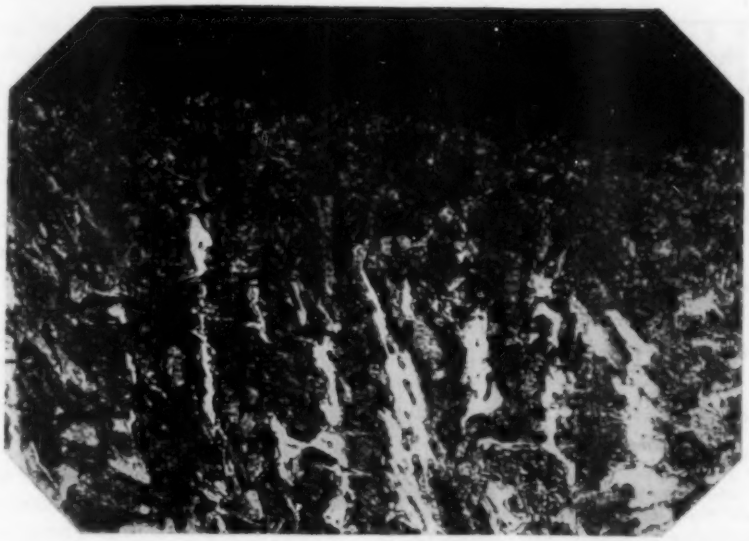


Fig. 11—Austenitic Layer Frozen at Surface of White Cast Iron. × 250. (Now Decomposed to Sorbite.) Eutectic Cementite in Interior. (Hedberg in Author's Laboratory.)

In general, such free energy curves are related somewhat, as in the preceding figure. They can, however, take such a form that the solid phase consists of a pure substance. This condition is rather closely approached in the case of the alloys of lead and tin, lead and antimony and many others. Such systems have a very limited solubility, practically none in the solid state, though the metals are mutually soluble in all proportion in the liquid state. A few cases exist, not often of importance to foundrymen, in which there is not complete solubility in the liquid state. Many alloys exhibit unlimited solubility in both the solid and liquid state. This is true, for instance, of copper-nickel, copper-gold, and many others. The most common condition of all is one exemplified by the iron-carbon alloys in which a temperature is suddenly reached at which the last remaining liquid, still containing both components, freezes as a two-phase solid.

Why solid solubility does or does not exist is related fundamentally to the crystalline structure of metals. Most of the commercial metals have their atoms arranged in one of two patterns, the face centered cubic or the body centered cubic. Obviously if there is to be complete solubility, the metals must have the same type of lattice. It is also necessary that the sizes of the atoms of the two elements be not too far apart. The "atom diameter," or better, the distance of closest approach of atomic nuclei in the pure metals, should not be much more than 12 per cent different, or solid solution will be limited. Furthermore, the elements must not be too far apart horizontally in the periodic table or they are likely to form chemical compounds instead of solutions. For our purpose we are but little concerned with these very important and fundamental considerations.

Phase Diagrams

As practicing metallurgists, we express the compositions of the phases present as a function of concentration and temperature in the well known equilibrium or phase diagrams. These have been worked out, usually with considerable precision, for all the binary alloys of the common and commercially important elements and many others. They can be found in the literature. For the purpose of illustration we will deal only with a somewhat simplified form of the iron-carbon diagram shown in Fig. 10. In this diagram, with temperature as an ordinate, carbon concentration as an abscissa, the lines map out areas in which the system is of one or of two phases. The equilibria involving delta iron have purposely been omitted from the diagram. This omission is not justified except as a matter of schematic simplification. For our present study we need concern ourselves only with that field marked γ + liquid. As indicated by this marking in the range of concentration and temperature mapped out by the heavy lines constituting the boundary of this field, the metal is partially frozen to solid γ iron and partially still molten. If we select any temperature and draw through

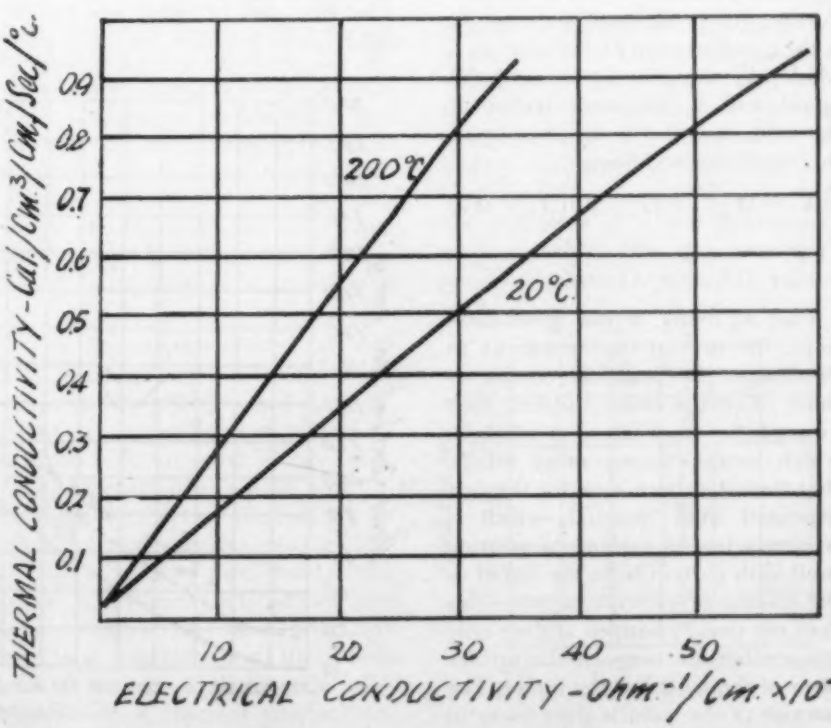


Fig. 12—Relation of Electrical and Thermal Conductivities of Various Copper Alloys at Two Temperatures. (Smith and Palmer.)

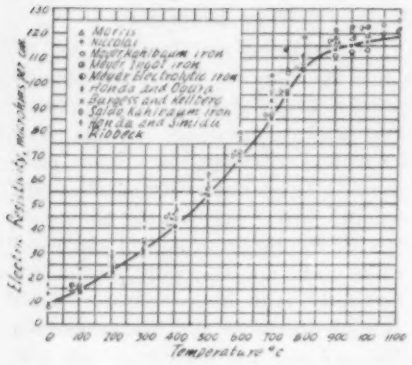


Fig. 13—Electrical Resistivity of Approximately Pure Iron at Various Temperatures. (Compiled by Cleaves and Thompson.)

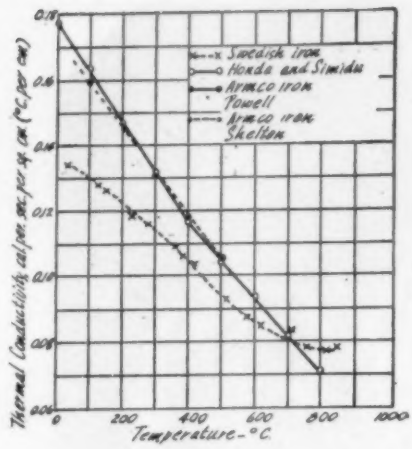


Fig. 14—Thermal Conductivity of Approximately Pure Iron at Various Temperatures. (Compiled by Cleaves and Thompson.)

it a horizontal line (an isothermal), it will intersect the two boundaries of the two-phase field (the solidus and the liquidus). The two points of intersection mark the composition of the solid substance and the liquid substance in equilibrium with each other.

Confirming what was said immediately above with regard to the free energy lines, these two compositions change with every change of temperature. We can, however, very readily say for a given temperature, that if the composition of the alloy as a whole is known, then the relative amounts of solid and liquid must be such that when multiplied by their respective concentrations, the right alloy composition is obtained. Putting this in algebraic form, if X_0 is the concentration of the alloy as a whole, X_1 the concentration of the liquid, and X_2 the concentration of the solid, then if y is the fraction of the total alloy solidified,

$$y(X_2 - X_0) = (1 - y)(X_0 - X_1)$$

$$y = \frac{X_0 - X_1}{X_2 - X_1}$$

Like so many of our generalizations, the present one is subject to disturbance by practical considerations. The discussion assumes that complete equilibrium is reached, which means, among other things, that there has been time for the first deposited solid material, which is relatively low in carbon, to saturate itself with carbon from the liquid as the cooling goes on very slowly. This does not usually happen and we only get equilibrium between the surface layer of the solid and the liquid. The interior of the solid is then lower in carbon than the equilibrium conditions predict, so the average composition of the solid layer is less than the equilibrium requirement and the X_2 of the preceding equation is lower than the correct one. This means that we actually have more solid matter than the theoretical calculation requires. How much more depends upon the freezing rate.

Selective freezing may cause differences of composition between the center and surface of a casting. Thus the thin outer layer of a white cast iron object consists only of the decomposition products of austenite, no eutectic having frozen next the surface, as shown in Fig. 11.

In the case of those systems in which there is either no solid solubility, or unlimited solid solubility, the phase diagrams can be calculated with a greater or lesser approach to accuracy from the thermodynamic properties of the components. The correct treatment of this subject involves a knowledge of the molecular weights of the substances in liquid and solid solutions. It has been frequently argued that the metallic elements are monatomic under these circumstances. The arguments have much in their favor. This writer, however, was much gratified by Chipman's Campbell lecture in 1942, in which he pointed out that some things which were considered to be departures from simple thermodynamic principles underlying solutions could, in the case of slags, be justified by assuming the existence of various molecular compounds. The writer has long held that this viewpoint should not be neglected in the study of metallic equilibria.

There is a law, known either as van Laar's or Schroeder's, which says that

$$L_n \frac{X_1}{X_2} = \frac{L_f}{R}\left(\frac{1}{T_f} - \frac{1}{T}\right)$$

in which X_1 and X_2 are the mol fractions of a component in the liquid and solid phases respectively. L_n is the symbol for the natural logarithm. L_f is the latent heat of fusion of the pure component. R is the gas constant (about two calo-

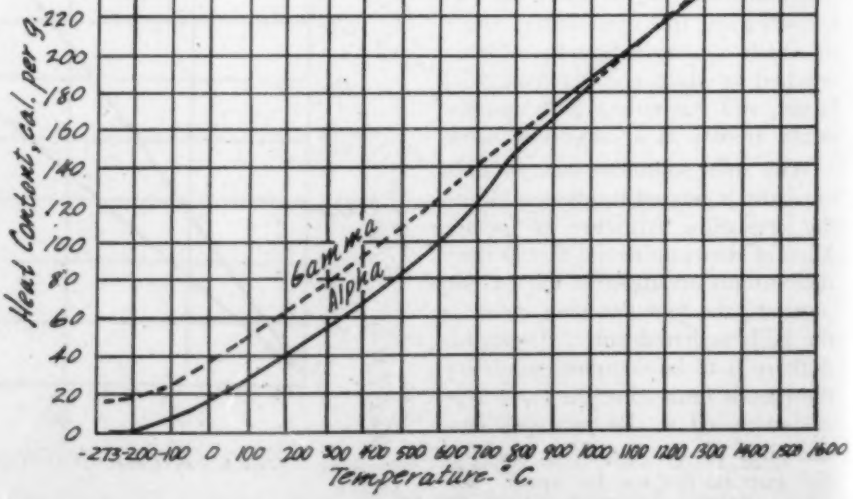


Fig. 15—Heat Content of Face Centered and Body Centered Iron Above the Absolute Zero as a Function of Temperature. (Compiled by Cleaves and Thompson.)

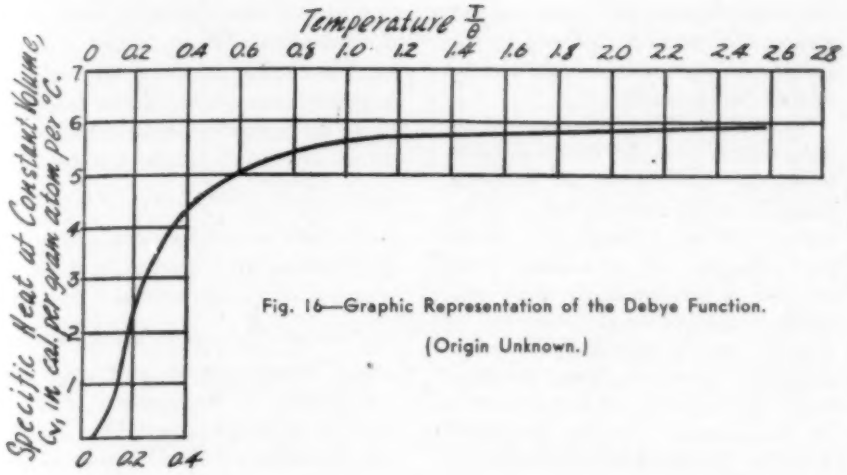

Temperature T/θ
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8
Specific Heat at Constant Volume, Cv, in cal. per gram atom per °C.
1 2 3 4 5 6 7
0 0.2 0.4

Fig. 16—Graphic Representation of the Debye Function.

(Origin Unknown.)

ries). T_t is the melting point of the pure component and T the experimental temperature. If the pure component is freezing out, then X_2 becomes unity and it is possible to calculate the composition of the liquid, X_1, as a function of T. If there is unlimited solid solubility, then there are two van Laar equations; one for each of the two components, and each, of course, using the latent heat of fusion and temperature of fusion appropriate to its own component. Then it is further true that the sum of the mol fractions of the two components must be unity in each of the two phases, which gives a sufficient number of equations for calculating the composition of the solid and liquid phases for any desired temperature.

The principles here developed could be expanded with increasing complexity to include systems of more than two components. Nearly all commercial alloys do have more than two components present in sufficient amount to affect freezing conditions. For engineering purposes it is, however, generally prohibitively difficult to analyze these rigidly. One usually adopts the dangerous practice of reasoning from what a similar binary or, at most, ternary alloy would do, in deciding matters of a practical character. If this is done with caution, it probably introduces no greater errors than those that creep in from other causes. One must, however, remember that he is not dealing in such cases with exactly the system he actually uses, and should be on the lookout for important discrepancies. Most reasoning regarding the freezing of iron alloys has indeed been based on the freezing of pure iron-carbon alloys, except where consideration must be given to the composition of two phases during selective freezing. It may be well at this point to leave our study of the freezing process as such, and devote a little attention to the physical properties of substances which are of interest in considering solidification of metals from those viewpoints important to the foundryman.

Physical Properties Which Influence Heat Transfer

The physical properties of substances which require consideration for our present purpose are: (1) those which influence the transfer of heat from the liquid metal to the surrounding mold material; (2) the dimensional changes which accompany changes of temperature and changes of state; and (3) those properties of the liquid metal which influence its ability to fill up voids which would otherwise result from the decrease in volume when a hot liquid metal becomes a cooler solid metal.

The determination of k at very high temperatures is experimentally rather difficult. The actual data are, therefore, somewhat scanty and of not too high an order of precision. Much work has been done with regard to the thermal conductivity of alloys at temperatures usually considerably removed from the melting point. J. B. Austin has summarized information of this kind. One may say, as a generalization, that alloys in which there is slight solid solubility have a thermal conductivity nearly equal to the weighted average of the conductivities of the two phases. Solid solutions may be expected to have somewhat constant conductivities over most of their composition range, and this conductivity will be decidedly less than that of either component in the pure state. There are theoretical relationships shown in Figs. 12, 13, and 14 between thermal conductivity and electrical conductivity, which are sometimes useful for the purpose of extrapolating the former to temperatures where direct experiment is inconvenient. Where no allotropic changes are involved, the electrical resistance of a metal can usually be extrapolated by using an equation of the form

$$R = a + bT \times cT^2$$

where R is the electrical resistance, T the absolute temperature and a, b and c numerical constants which can be determined by observation in a temperature range where precise measurements are possible.

The law of Wiedemann and Franz, discovered experimentally nearly 100 years ago, stated that the ratio of electrical conductivity to the thermal conductivity (at any given temperature) was constant, irrespective of the metal. It has since been found by theoretical calculations that

$$\frac{K}{\sigma} = \frac{\pi^2 R^2}{3e^2 N^2} T$$

Here K is the thermal conductivity, σ the electrical conductivity, R the well-known gas constant, and e is the charge on the electron (a very basic constant). T is the absolute or Kelvin temperature. This equation confirms the experimentally observed law and adds to it that the ratio is proportional to the absolute temperature. Setting numerical values

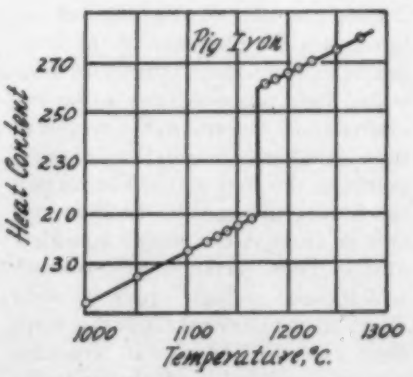


Fig. 17—Heat Content of Cast Iron Near the Melting Point and Latent Heat of Fusion. (Japanese Data.)

for the constants, the coefficient of the ratio of the two conductivities should be $0.585T \times 10^{-8}$, a value which is closely approached for most of the metallic elements. All of the assumptions are with respect to the solid state. No doubt we are going rather far from our basic subject, but some reference to the inter-relation of the properties we are using should be of value to those intending to pursue our subject.

The electrical analogy can not of course be used practically for work with refractories which are, in general, rather good insulators. Also the electrical resistance of molding sand is more nearly a function of its water content than of the actual resistance of the mineral matter, and this water content has relatively little to do with conductivity at these temperatures in which we are interested. It will, no doubt, be plain that when heat is transferred, according to Fourier's law, the heat units passing on serve to heat the substance into which they are being conducted; the amount of this heat depending upon the heat capacity of the substance per unit volume. When such heat transfer has taken place, the temperature gradient has altered, and we have to know what the effect upon the gradient has been. For this purpose we use a physical concept called "diffusivity" and represented by the symbol h^2. The use of the second power in this symbol is a matter of minor convenience, because in many formulae the square root of this constant applies. At any rate let the reader remember that the diffusivity of the material is represented by h^2 and that this constant is equal to the quotient obtained when the conductivity of the material is divided by the product of its density and specific heat. Both the density and the specific heat of all substances are functions of the temperature. Here again difficulties arise when these properties are to be experimentally determined at temperatures comparable with the melting points of the iron alloys. For certain substances the specific heat is calculable from rather simple considerations. Those crystalline substances which have a high order of symmetry in their crystal habit can have their specific heat (at constant volume) calculated theoretically. Fortunately most of the solid metals have a lattice arrangement which is some modification of a cubic system. Almost all of these fall within the group of substances which can be treated theoretically.

Some other fairly symmetrical arrangements also fit the conditions reasonably closely. It is, however, unfortunate that the industrially important element, iron, due to its particular atomic structure, is not capable of treatment by these relatively simple physical concepts (see Fig. 15), nor is graphite. The mathematical physicists have struggled with the problem of expressing in an equation the relation of specific heat to temperature in these symmetrically crystalline substances. The best known relation is the so-called "Debye function." This seems to meet every need, although further refinements have been proposed. The mathematical form of the Debye function is probably terrifyingly complex for our present use. It can, however, be expressed in the form of a curve, as in Fig. 16. This graph gives the heat content per gram atom per degree at constant volume in terms of the relation between the absolute temperature T and a constant θ having the same dimensions as temperature which can be thought of as the temperature at which the substance has a particular specific heat $\frac{3}{2} R$. This constant θ is rather easily and accurately determined by determining the specific heat at a series of temperatures which bracket the value $\frac{R}{2}$, and interpolating. Once determined, it permits of the calculation of the specific heat at any other temperature. One of the characteristics of the Debye function, which it must have to represent the observational facts, is that the atomic heat (specific heat times atomic weight, or heat content per gram atom per degree) should approach $3R$ where R is the gas constant, and about two calories. Substances having low values of θ approached this value of true specific heat at lower temperatures than in the reverse case. This approach to a value of about six calories was known long

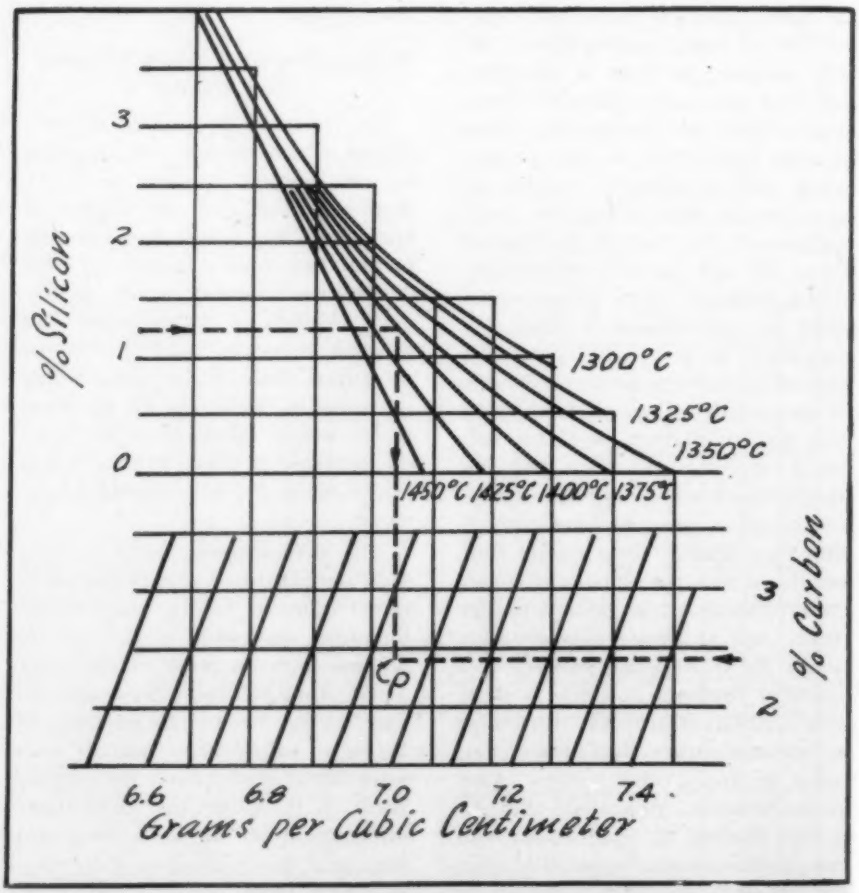


Fig. 18—Density of Liquid Cast Iron as a Function of Carbon and Silicon Content and Temperature. (Measured by Gorton and Austin in the Author's Laboratory.) The Dash Line Shows How to Determine the Density at 1400° C. of an Alloy Containing 1.25 Per Cent Si and 2.4 Per Cent C.

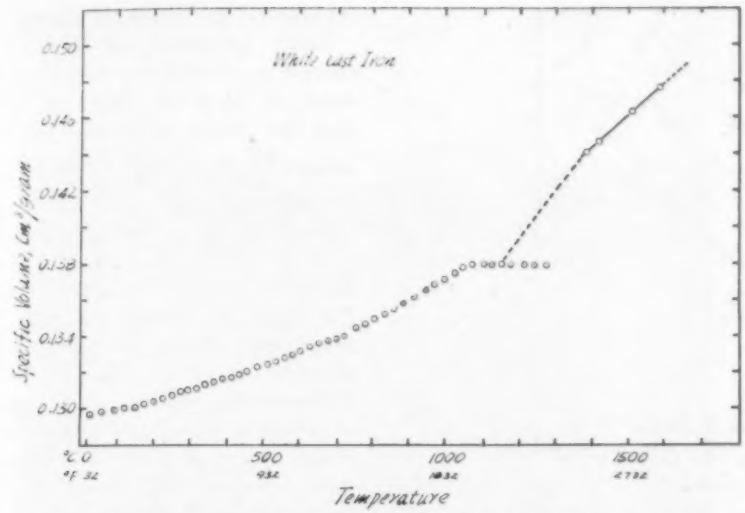


Fig. 19—Specific Volume Temperature Relation of Solid and Liquid White Cast Iron. (Ash and Saeger.)

before any theoretical basis had been established and found a place, even in quite early text books, under the name of Dulong and Petit's Law. It is limited to crystalline substances and can not be applied to liquids of any kind, or to non-crystalline substance such as glass, and many slags. For such substances direct experimentation must be resorted to if the constants are to be determined.

The specific heat of liquids is very commonly pretty nearly independent of temperature, which may, in part, be due to the fact that the temperature range within which many substances can remain liquid is not very long.

Latent Heat of Fusion

Since we are dealing with the freezing process, the most important thermal property of a metal for our purpose is its latent heat of fusion. This is the heat energy which is required to overcome the attractive forces between adjacent atoms in a crystal lattice, and cause the atoms to move independently of one another, while not having become much more widely separated than in the solid state. For many substances it has been determined calorimetrically, sufficiently well at least for engineering uses (Fig. 17). There is a rule called "Trouton's" which has undeservedly fallen into disregard, which says that the ratio of the latent heat of fusion per gram atom (in calories) to the melting temperature (Kelvin scale) is nearly constant and about 2.2. In more high-brow and modern language one might say more impressively that the entropy of fusion of most substances is nearly the same, about 2.2 calories. This generalization, while not precise enough for many purposes of the physical chemist, is, in many cases, a useful aid to the engineer.

We may lastly add the statement that specific heats are additive in alloys and in chemical compounds (unless some of the substances in the pure state are gasses). This generalization again, while not sufficiently accurate for thermodynamic use, is generally good enough for engineering purposes. The physical chemist will recognize that if it were rigidly true, there would be no free energy of combination or solution, which is, of course, an absurd consequence. The use of Kopp's rule, as suggested above, must be limited to uses where approximations suffice.

One may also remember that the heat required to bring a system from one state to another is independent of the path by which one goes between the initial and final condition. This rule is convenient where, because of the presence of alloys, an element melts at a temperature above or below its normal melting point. The total heat which must be imparted to a substance to bring it from the solid state at a temperature below the melting point, to the liquid state at a temperature above the melting point, is the same, regardless of the temperature at which melting can be caused to occur. In any event we have the sensible heat of the solid substance from its initial temperature to the melting point, plus the latent heat of fusion at the melting point, plus the sensible heat of the liquid from the melting point to the final temperature. The latent heat of fusion, therefore, differs with the temperature if the two specific heats (for the solid and liquid) differ. All of these facts, with the relations of the thermal properties of substances, are of importance in considering the freezing of liquid metals. We have not nearly exhausted the subject but may have so far exhausted the reader's patience as to make further discussion of the physics of heat undesirable for the present purpose.

Change of Volume on Solidification

Leaving this portion of the subject then in its somewhat disjointed form, we turn to the question of the change of volume which occurs when metal goes from the liquid to the solid state. The change in volume produced when a superheated liquid

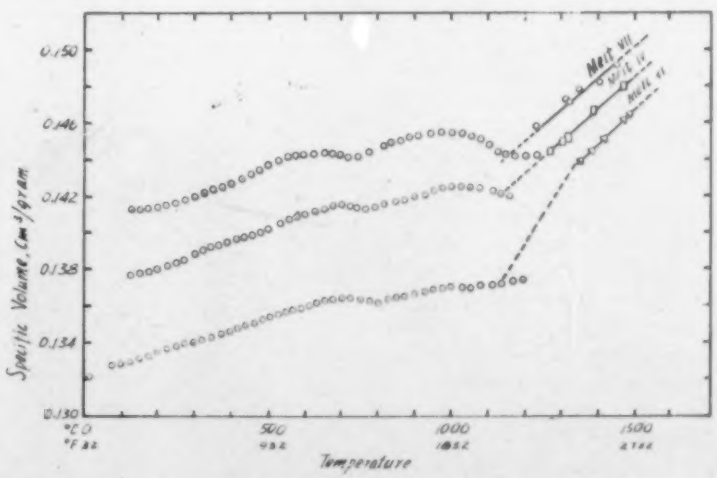


Fig. 20—Specific Volume Temperature Relation for Three Gray Cast Irons in the Solid and Liquid States. (Ash and Saeger.)

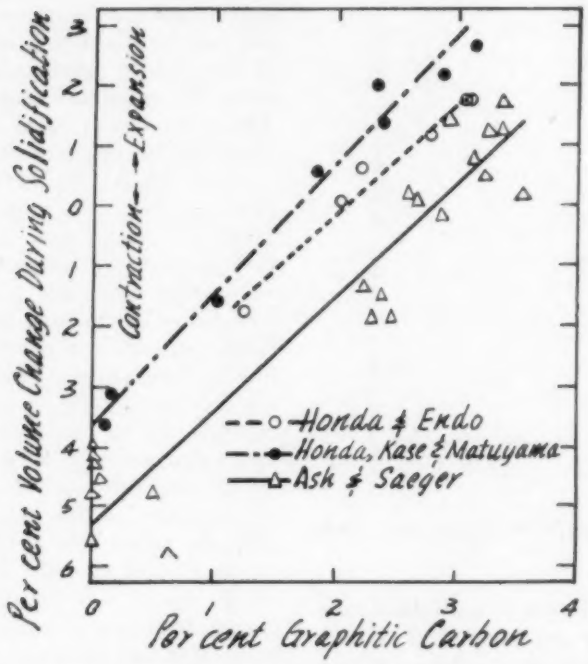


Fig. 21—Volume Change on Solidification of Graphitic Irons. (Ash and Saeger.)

becomes a solid at a temperature below the melting point, is made up of three portions: the contraction of the liquid in cooling from its original temperature to the melting point; the change of volume occurring on freezing, supposed to take place at constant temperature; and the change of volume of the solid in cooling from the melting point to some chosen final temperature. Certain special considerations must be taken into account if freezing takes place selectively over a temperature range and not isothermally as presupposed in our simplified statement.

All who have observed a mercury thermometer will have made use of the fact that the amount by which a given bulk of liquid metal expands for a given increase in temperature is, apparently at least, independent of the temperature. This co-efficient of thermal cubic expansion is, however, different from one liquid to another. The subject has not been particularly completely investigated and, in general, our knowledge of the co-efficient of expansion of commercial alloys in the liquid state is rather defective. Gorton and Austin in the author's laboratory obtained the results shown in Fig. 18 for cast iron. Such information as there is, is largely of a purely experimental character. Some of the most important work of this kind, from an industrial viewpoint, was done under the supervision of the American Foundrymen's Association, by Ash, at the Bureau of Standards, under the direction of Saeger. Figs. 19, 20 and 21 are taken from this work. Those who are interested in the behavior of the cast irons will find the work a source of most useful information. Most substances expand on liquification. The most glaring exception is ice, but bismuth, antimony and alloys of the type-metal group also expand on freezing. Cast iron, at least in the commercial range of carbon content, actually freezes as white cast iron, but almost at the moment of freezing, probably within a relatively few degrees above or below the freezing temperature, the iron carbide of the white cast iron decomposes into an iron-carbon alloy and excess graphite, with an increase of volume of 0.18 cubic centimeters per gram of carbon.

Fig. 22—Expansion of a Pure Iron Carbon Alloy on Freezing. (Author's Laboratory.)

Endo measured the change in volume accompanying melting for a series of elements and concluded that the change in volume per unit weight $\frac{\delta V}{W}$ shown in Table 1 is a periodic function, as is the atomic volume. Qualitatively this is true but a very cursory comparison shows that there is no quantitative relation. For example, aluminum, gold and silver have almost the same atomic volumes.

Figure 22, which is a photograph of a nearly pure high carbon alloy, slowly frozen in a vacuum furnace, demonstrates this condition very well, although here some of the graphite formed at the moment of solidification above the eutectic melting point. The formation of this graphite, with the accompanying increase in volume within the already frozen outer shell, has extruded a spherical drop of liquid metal through a hole punctured by internal pressure in the upper surface. The thermal expansion of solid metal has been measured for many alloys by rather simple and well-known methods. The results are given usually as a coefficient of linear expansion which, for our purpose, is not so convenient as a coefficient of cubic expansion. Since the changes of volume are small, it is, however, easy to transfer from one system to another on the principle that the cubic coefficient is almost exactly three times the linear coefficient. The changes of volume, accompanying the change of state at the freezing point, have almost universally

Table 1

CHANGE OF VOLUME PER UNIT WEIGHT

Element	*Symbol*	$\frac{\delta V}{W}$
Mercury	Hg	0.00263
Rubidium	Rb	0.0168
Potassium	K	0.0310
Sodium	Na	0.0267
Tin	Sn	0.00386
Bismuth	Bi	—0.00351
Thallium	Tl	0.00282
Cadmium	Cd	0.00574
Lead	Pb	0.00320
Zinc	Zn	0.010
Antimony	Sb	0.0022
Aluminum	Al	0.02434
Silver	Ag	0.0051
Gold	Au	0.00282
Copper	Cu	0.0043
Iron	Fe	—0.0085

Fig. 23—Interdendritic Voids in the Partially Frozen Zone of a Steel Casting Where the Temperature Is Between the Liquidus and the Solidus. Outlines of the Dendrite Are Confused by Entrapped Liquid. Dark Outer Band Is the Surface of the Frozen Layer. × 4. (Courtesy of Ken L. Clark, Naval Research Laboratory.)

been determined by extrapolating from observations in the solid state to obtain the density of the substance just before melting begins, and extrapolating from observations in the liquid to obtain the density when melting is just completed. The charge of volume accompanying the change of state can be calculated from the difference of these two densities. In extrapolating to obtain the density of the solid metal, use may well be made of the principle that the coefficient of thermal expansion of a given substance in proportional to its specific heat, regardless of the temperature. In many cases of non-ferrous alloys, the Debye function can give us the relation of specific heat to temperature. This, with the above principle, which was experimentally verified by Grueneisen, permits of more accurate results than mere linear extrapolations.

For those commercial alloys which freeze selectively, this change in volume takes place over a temperature interval. Here we have an important matter for the foundry. When this metal is partly frozen it consists of a mass of tree-like growths, with liquid metal between the branches where air is, in the case of real trees. (See Fig. 23.) As further cooling takes place with accompanying freezing of this remaining metal, the latter decreases in volume more than the spaces which it originally filled, because overall dimensions of these spaces decreased only as determined by the thermal coefficient of cubic expansion of the solid. Two things can happen. Either liquid metal can run in from somewhere else, or inter-dendritic voids can form, which may even be of microscopic sizes. Consideration of this effect is necessary in making arrangements to feed a casting, for it is quite possible to fill up all the gross shrinkage voids without really filling up the interdendritic shrinkage. The writer has had occasion to observe that spheres cast experimentally from various white cast iron alloys have the same apparent density, whether they showed evidence of gross internal shrinkage by x-ray methods or not. The explanation is merely that if the shrinkage does not all go to one place and show up as a dark area on the x-ray plate, an equal volume distributes itself so finely throughout the entire volume of the test body as not to be detectable in any one place. Sachs has found the resistance to penetration by x-rays a useful means of determining existence, especially in light metal alloys, of alloys suffering from such widely distributed fine porosity. One of his x-rays is shown in Fig. 24. In the case of magnesium alloys, correlations have been drawn between this phenomenon and the tensile strength of the resulting specimens. It is also possible to apply this method to steel. A thin slab of uniform thickness, machined from a steel casting, frequently—or one might say usually—shows difference of density on an x-ray negative, even in the absence of distinguishable discreet voids.

The x-ray technique has even been applied to micro-examination as shown in Fig. 25.

The extent to which feeding, by eliminating various types of porosity, may improve the properties of a casting, is shown by the fact that a certain part stretched one-third more when proof-tested under given conditions when one of two feeders was eliminated.

Flow of Metal from Feeder to Voids

If we are to consider the solidifi-

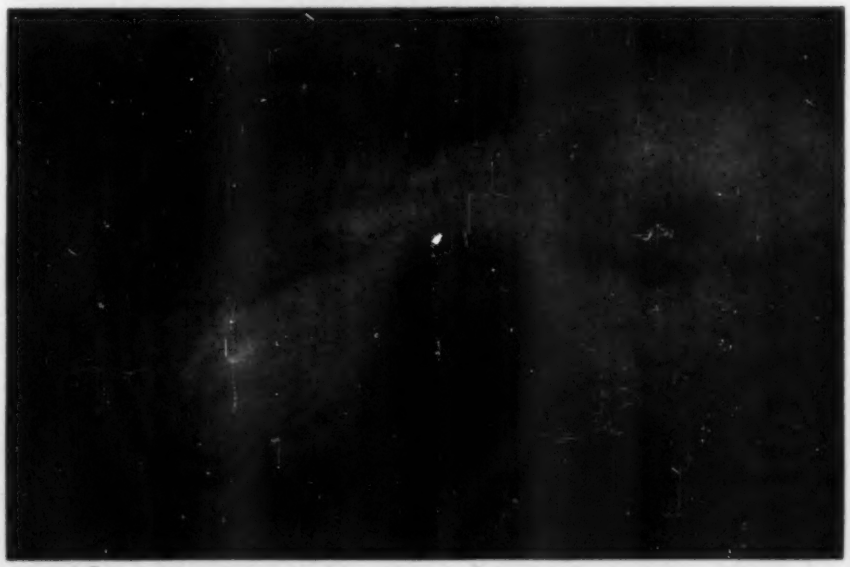


Fig. 24—X-ray Negative Showing Inter-Crystalline Porous Areas (Dark) in Magnesium. (Courtesy of Geo. Sachs.)

cation of metals in any way of practical utility to the foundryman, we come, sooner or later, to the consideration of the flow of metal from a feeder or other source of liquid into voids, be they in the form of large shrinkage cavities of intergranular microscopic fissures. We may know as much as we please about why and where and how voids form but we cannot do anything about it unless we study the means of admitting liquid metal to supply the deficiencies.

Before we can profitably consider the properties of the liquid metals which are of importance in this connection, we must arrive at an understanding of the laws governing the flow of liquids in pipes or channels. It is therefore necessary to make a brief excursion into the science of hydraulics. The flow of liquids in pipes has been studied for a very long time. Bornoulli, in the middle of the 18th Century, gave a satisfactory analysis of the flow of water in smooth pipes. The investigation was later extended by others to cover the effect of friction of liquid against the pipe wall. In all of these cases the liquid was supposed to move as a single body through the pipe, much as a solid plug might move. Now, especially in the case of metals flowing in a container of the same material which has frozen against the wall of the mold, these principles do not suffice. We have already touched upon the fact that the inner surface of a partially frozen body is covered with a lot of tree-like growths, which virtually anchor the surface layers of the liquid metal to the walls of the frozen material. The adhesion of liquid to solid adds to these forces.

The surface layer of metal in contact with the solid matter probably moves forward not at all. The layers further in move forward, each layer with a higher velocity than that outside, until the center thread of the stream moves forward fastest of all. The metal thus advances by a process which might be likened to its continually turning itself inside out, somewhat the reverse of the mythical snake swallowing itself, beginning with its own tail. The velocity of flow of liquid metal under our conditions is, therefore, determined by the ability of successive layers to slide with relation to each other when a force is applied to them. The property of a material which resists such flow is called "viscosity." The quantitative measure of viscosity is schematically illustrated in Fig. 26. Here we have two parallel areas, each of unit magnitude, separated by unit distances in a viscous liquid. If we can conceive of taking hold of these areas, which are separated by unit distance, keeping one stationary and moving the other parallel with itself, at unit velocity, then the viscosity of the

Fig. 25—Micro-Radiograph of Voids in Sound Cartridge Brass. × 100. (Maddigan and Zimmerman. Courtesy of A.I.M.E.)

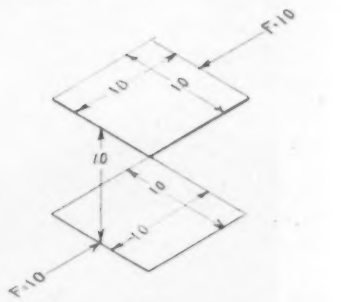


Fig. 26—Schematic Diagram Defining Viscosity in a Liquid.

liquid is equal to the force required to produce this velocity. For a given viscosity, if we double the force, we double the velocity. A given velocity at unit distance is equal to half that velocity at a distance of separation of the two areas of half the unit of linear measurement. Viscosity is represented by the Greek letter η.

It is quite simple, by the use of calculus methods, to determine the velocity of flow under a given pressure along any cylindrical shell concentric with a cylindrical pipe, or what is of greater utility to compute the mean velocity of flow across the entire cross-section of pipe, suitably weighting the zero velocity at the circumference, the maximum velocity at the center and the various velocities at different radii between. By such computation we get the expression

$$v = \frac{\pi P R^4}{8 L \eta}$$

Here P is the intensity of pressure of the liquid in the pipe, R is the radius of the pipe, L its length and v is the *mean* velocity of flow for a liquid of vicosity η. It is, of course, necessary to be cautious about using a consistent group of dimensions. The scientist prefers to express everything in the c.g.s. system, in which the cm., the gram, and the second are the fundamental units. The unit of pressure is then dynes per square cm. and η is in dynes. Evidently if we prefer to talk about grams per sq. cm., the equation will remain consistent if we express η in grams also, or we can, at considerable inconvenience, translate into the exceedingly inconsistent British-American units.

Then similarly if the flow is to be not through a cylindrical pipe but between two parallel plates, separated by $2R$ from each other, then the mean velocity comes out as

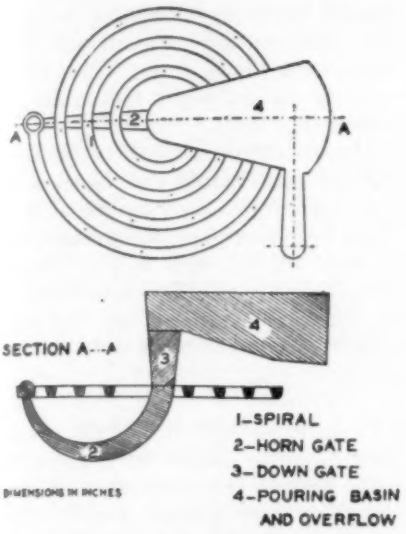


Fig. 27—Fluidity Pattern Assembly. (Saeger and Krinitzky.)

$$v = \frac{PR^3}{3L\eta}$$

The latter equation is of importance if metal is filling up a flat slab; the former if it is running down a cylindrical passage, as, for example, through a feeder mouth.

The amount of metal which will flow through a passage in unit time is evidently the mean velocity of flow, times the cross-sectional area of the passage. If our shrink voids are to be filled up, the amount of metal flowing in unit time must be such as to fill up the voids before enough time has passed for the metal to solidify in the passage through which it flows. Actually this problem becomes somewhat complicated because as the metal flows, it probably cools, its viscosity increases, some material freezes to the walls and the cross-sectional area through which the metal must flow is constantly decreasing. Both R and η, in the expression given above, are thus functions of time (because temperature is a function of time and these properties are functions of temperature). A rigid analysis of what goes on under these circumstances is, therefore, too complicated mathematically for profitable treatment. In practice the foundryman measures a sort of integration of all of these properties by the use of the well-known fluidity spiral, illustrated in Fig. 27. Unfortunately there has been more originality in the development of the design of these spirals than consistency in their use. As a consequence it is decidedly difficult to compare data obtained by different observers. What the spiral actually does is cause the metal to flow into a long, slender passage at constant rate. As the metal flows along it cools; the cross-sectional area of the passage decreases; the viscosity increases; the metal flows more slowly; and so on, until the viscosity finally becomes so high, when freezing begins, that the metal can no longer advance. The fluidity spiral thus measures a combination of the degree of superheat of the metal when poured, and the viscosity-temperature relation. Although it is not a particularly scientific procedure, it is calculated to give the foundryman almost exactly the information he requires as to the ability of the metal to flow. In this regard it is like many other practical measurements; extremely complicated in principle, but so closely related to the property which makes the material useful that it constitutes an excellent criterion for judgment of quality.

In Fig. 28 we give an example of the effect of composition on the castability of the iron-carbon alloys as a function of carbon at a single temperature.

Table 2

CHANGE OF VISCOSITY WITH TEMPERATURE (CAST IRON CONTAINING ABOUT 3.8 PER CENT CARBON)

$\frac{T\ (abs.)}{T_s}$	η
1.02	0.0275
1.04	0.0239
1.06	0.0213
1.08	0.0188
1.10	0.0169
1.12	0.0154

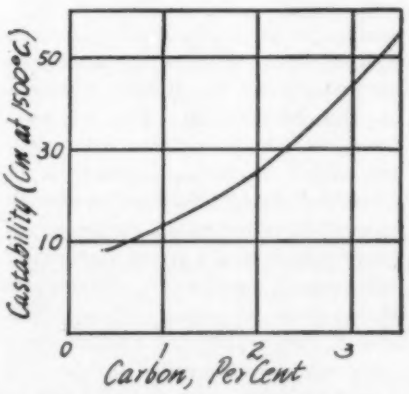


Fig. 28—Relation of Castability to Carbon Content. (Author's Compilation from British Data.)

Table 3

CHANGE OF VISCOSITY WITH TEMPERATURE FOR TIN, ZINC, AND BISMUTH

Element	$\frac{T}{T_s}$	η
Sn	1.005	0.0275
	1.07	0.0235
Zn	1.11	0.0165
	1.28	0.0135
Bi	1.05	0.0162
	1.18	0.0145

Viscosity of Liquid Metals

For scientific purposes we should really have somewhat more systematic information. The viscosity of liquid metals is different and is a function of temperature, decreasing as the temperature rises. It has been shown that a direct relationship exists between the change in viscosity and the change in volume with the temperature of a liquid. In the case of metals it has been suggested that viscosities can be better compared if we use as a basis, not the temperature of the liquid itself, but the ratio of that temperature to the liquidus temperature (the temperature at which the alloy *begins* to freeze). For a cast iron containing about 3.8 per cent carbon, viscosities were found to change with temperature, as shown in Table 2.

A decrease in carbon to about 2.7 per cent raised these values by about 2 per cent, and an increase to 4 per

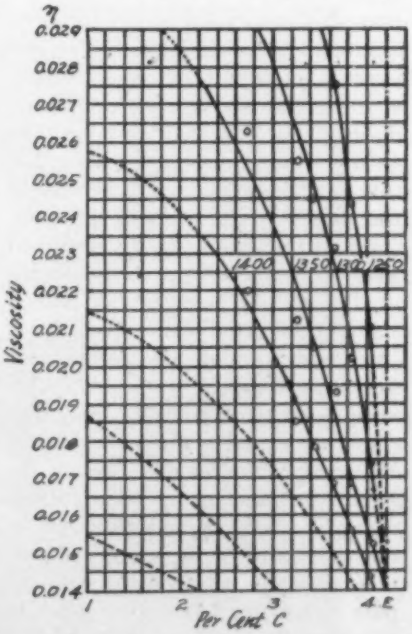


Fig. 29—Viscosity of Iron Carbon Alloys at Various Temperatures. (Thielman and Wimmer.)

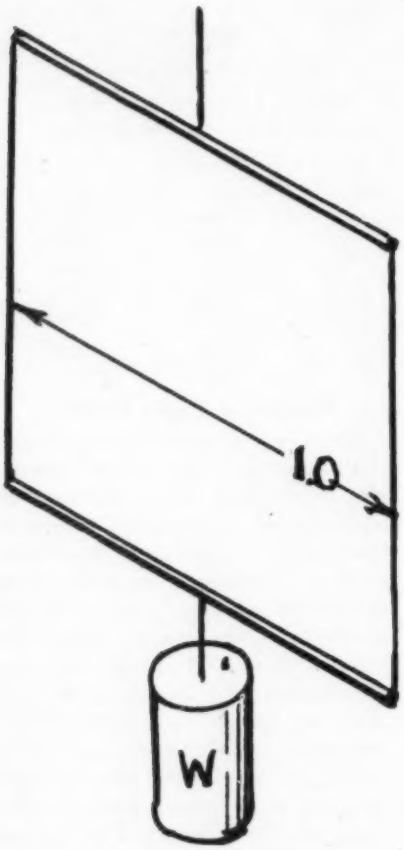


Fig. 30—Schematic Diagram Surface Tension of a Liquid.

cent carbon decreased them about 5 per cent. Observations on tin, zinc and bismuth gave data which have been summarized in Table 3.

Figure 29 gives data for cast iron. It is, perhaps, not to be expected that the agreement should be too exact in the determination of the viscosity of liquid metals, especially at high temperatures, which is quite difficult. However, when compared on the basis of the relative temperature here suggested, the viscosity of the metals is not so very different.

So far we have tacitly assumed that there is no limit to the smallness of the passage through which a liquid will flow. In a sense this is true. However, passages can become so small that the expressions for mean velocity quoted just above, become meaningless because of the effect of surface tension. This is the same phenomenon as the "surface energy" which we encountered in the discussion of the effect of particle sizes on the melting point of pure substances. When we refer to it as surface energy we visualize it as being the energy (ergs) required to increase the surface of a substance by unit area (cm^2). Actually we should not say the surface of a substance but area of bounding surface between two phases.

Surface Tension

For some purposes we prefer to represent this phenomenon in terms of a force, surface tension, which is then best understood by the set-up shown schematically in Fig. 30. Here we have two weightless wires of unit length, with a thin film of liquid between them. The upper wire is held stationary. The load which the lower wire will sustain, without breaking the film of liquid, which, of course, has no tensile strength, is twice the surface tension of the liquid. (It is twice because we have a boundary on each side of the film.) The measure of surface tension is then force (dynes) per unit length (cm.), which is obviously the same expression as was written for surface energy, if the latter expression be divided through by the length unit. For all purposes in which we are interested, the effect of surface tension is to cause the liquid to behave as though it were included in an elastic membrane which had a particular breaking strength equal to the surface tension. Now we must actually talk about three different surface tensions when we consider the flow of liquid along a solid surface, and in air or any other gaseous atmosphere. Surface tension is commonly represented by the Greek letter σ. Let us consider $\sigma_{1\text{-}2}$ at the gas-liquid interface, $\sigma_{2\text{-}3}$ at the liquid-solid interface, and $\sigma_{1\text{-}3}$ at the gas-solid interface. Then it can be shown that the angle ϕ which the boundary between liquid and solid makes with the surface of the solid at the point of contact of all three phases, is given by the expression $\sigma_{2\text{-}3} = \sigma_{1\text{-}3} + \sigma_{1\text{-}2} \cos \phi$. Cos ϕ might come out either positive or negative. If positive, the liquid does not wet the solid and the surface of the liquid is convex as is the surface of mercury contained in a glass beaker. If cos ϕ is negative, then the liquid wets the solid and will run forward on the solid surface, as does solder on a clean copper plate.

Now let us assume that we are trying to have metal flow forward into a thin horizontal plate. The advance forward face of the metal, which all who have examined "cold-shuts" know to be convex, is held by the surface tension of the advancing liquid front. This force will be $2\sigma \cos \phi$ per unit width of advancing front.

Unless the product of the pressure on the metal times the thickness of the plate into which the metal is to flow is greater than this amount, the metal will not flow at all. If the flow is not into a flat plate but into a cylindrical passage, we find that the flow will not begin unless

$$\pi PR = 2\pi \cos \phi$$

The expression P used in the viscosity formulae should be reduced by the pressure required to overcome the surface tension forces. Our knowledge of the surface tension of liquid metals is quite poor. This is due to two causes. First, we are confronted with the ever-present difficulty of conducting measurements at the temperatures of liquid metals, except perhaps in the case of mercury, tin, cadmium and the like. In the second place, the surface tension of a liquid metal is enormously affected by impurities, such as metallic oxides and similar compounds, which are very difficult to exclude from an experimental set-up. If we had data based on such exclusion, they would not do us much good because the metals with which we deal would be more highly contaminated. The surface tension of a liquid decreases with its temperature, as all know who have found it easier to skid on a wet street when the weather is cold than when the weather is hot. This is shown in Fig. 31. It has been found that the thermal coefficient of viscosity is pretty nearly alike for all liquids

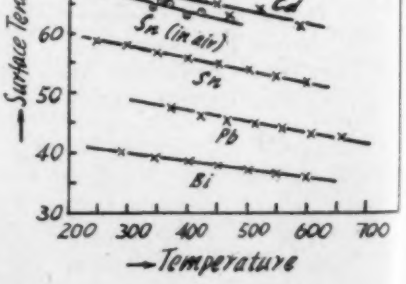


Fig. 31—Relation of Surface Tension to Temperature. (Matuyama.)

and at all temperatures and equal to

$$\frac{2.12}{V^{2/3}}$$

This coefficient is known as Eotvo's constant when V is the molar volume. It has been found that this coefficient for the metals tin, bismuth, lead and zinc, if they are assumed to be monatomic, comes out about 1.1 instead of 2.1. In organic liquids this would be regarded as fairly good evidence of polymerization. If the metals were triatomic, the results would be consistent.

In view of the fact that most of our knowledge of the surface tension of liquid metals is not any too accurate, the reader might perhaps content himself with the data of Matuyama for some of the metals at low melting points summarized in Fig. 31. Those who prefer a rough approximation to total ignorance may use the values of surface tension in milligrams per millimeter given in Table 4.

Table 4

SURFACE TENSION OF LIQUID METALS AT MELTING TEMPERATURES

Metal	*Surface Tension, mg. per mm.*
Silver	80
Copper	60
Gold	60
Iron	100

These figures make no pretense at accuracy, but may be useful as first approximations. Iron and copper particularly are subject to atmospheric contaminations, and the results on a commercial alloy may be very different and probably higher than those here quoted.

The orifices through which liquid iron will flow into voids in a solid heated to the melting point are surprisingly small. Fig. 32 shows the penetration of white cast iron into a super-heated core at a point where the core wash cracked.

If metal is to flow into a cavity, that cavity must either be entirely empty or there must be means for the escape of any gas which it contains. This occasions no difficulty so long as the cavity is large and the stream flowing into it small. A tumbler can be filled with water under a faucet without worrying how the air is to get out. It is much more difficult to fill a very small mouthed bottle with water by immersing it, mouth up, in a bucket. Surface tension keeps the air bubble from detaching iself from the mouth, if the latter be small enough, and consequently the water is kept from running in. This crude analogy is sufficient to demonstrate that the ability to cause metal to solidify without voids has some relation to the evolution of gas from that metal. There are those who have contended that gas evolution is the sole and sufficient explanation for the occurrence of porous shrinkage voids. The mechanism which they suggest is that as the metal freezes it evolves gas and this gas pushes some of the last remaining liquid metal out of the space between dendritic growths to other places in the mold. While this may be too drastic an interpretation, we can not ignore the possibility that the voids, which may have been complete vacua when formed, filled themselves with any gas which the metal can give up and so well entrapped this gas that the metal which wished to flow can not do so.

Gas Content of Liquid Metal

All this suggests that we must give least some passing attention to the gas content of liquid metal, to the change in solubility at the freezing point, and to the mechanism by which gas enters or leaves metal. Many, presumably all, commercial metals will dissolve gases from the atmosphere if time permits. The gases of most importance in this connection are hydrogen, oxygen, and nitrogen. The oxides of carbon play some role, although we need not pursue the details if we consider the three gaseous elements. The amount of an inert gas dissolved by a metal varies with the temperature and pressure. Hydrogen, nitrogen, and oxygen are diatomic. In such cases the solubility of the gas varies as the square root of its partial pressure in the adjacent atmosphere. Hydrogen and nitrogen presumably dissolve as atoms. Oxygen may be thought of as dissolving atomically and immediately combining with iron, forming FeO, using the iron alloys as an example. For every temperature and metallic alloy there is some partial pressure of the dissolved gas exerted in equilibrium with each concentration of that gas. When the metal solidifies, the solubility of the gas suddenly decreases very markedly, which is the same thing as saying that the partial pressure in equilibrium with the existing gas concentration suddenly rises very rapidly. Unless an appropriate pressure is applied to keep the gas in, it is evolved as bubbles at the moment of solidification so far as time permits. Quite often solidification proceeds rather too fast for the reaction to go to equilibrium.

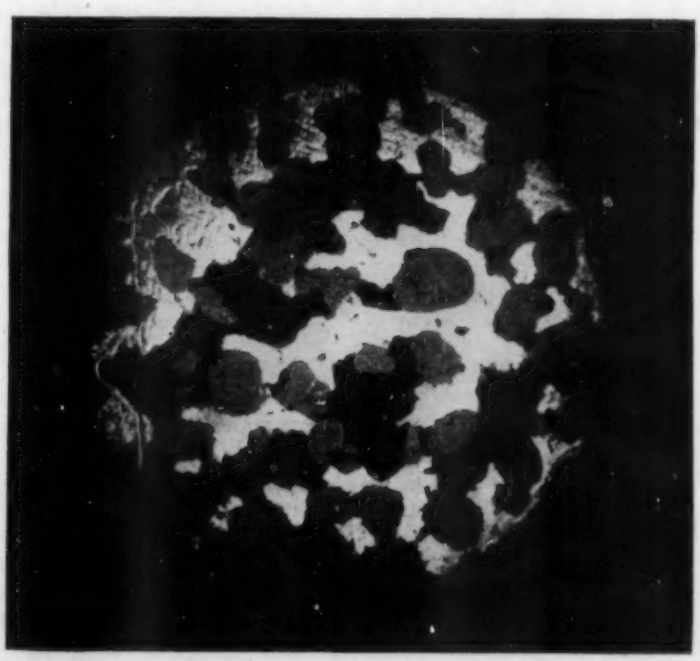


Fig. 32—Iron Intrusion in Sand Core. White—Cast Iron; Gray—Sand Grain; Black—Voids. (Halpern in the Author's Laboratory.)

Table 5

PARTIAL PRESSURE OF HYDROGEN IN EQUILIBRIUM WITH VARIOUS CONCENTRATIONS OF THAT ELEMENT IN MOLTEN IRON AND IN GAMMA IRON

(H), per cent	$P'_{(H_2,\ molten\ Fe)} = \frac{(H)^2}{K^2\,(H,\ molten\ Fe)}$	$P''_{(H_2,\ \gamma\ Fe)} = \frac{(H)^2}{K^2\,(H,\ \gamma\ Fe)}$
0.0020	0.670 atm.	4.54 atm.
0.0015	0.410 atm.	2.80 atm.
0.0010	0.167 atm.	1.13 atm.
0.0007	0.082 atm.	0.56 atm.
0.0005	0.042 atm.	0.284 atm.
0.0003	0.015 atm.	0.102 atm.
0.0002	0.0067 atm.	0.045 atm.

Chuiko give the partial pressure of hydrogen in equilibrium with various concentrations of that element in molten iron and in gamma iron, shown in Table 5.

It is quite readily seen that conditions which would retain 0.0005 per cent hydrogen in the molten metal would retain only about 0.0002 per cent hydrogen in solution in gamma iron. Whether or not these figures have any real quantitative significance, they indicate how hydrogen will wish to escape when liquid iron solidifies. A quick calculation, based on Sievert's data for the solubility of hydrogen in iron, exposed to hydrogen at one atmosphere pressure, indicates that at the moment of freezing, gas equivalent to some 15 or 16 times the volume of the liquid metal should escape. Admitting that furnace atmospheres contain only small concentrations of hydrogen, it is plain that we must give some thought to disposing of even the volumes of gas corresponding to commercial conditions. The data for nitrogen would be qualitatively but not quantitatively similar.

In the case of oxygen, which presumably dissolves as ferrous oxide, the partial pressure of carbon monoxide required to maintain equilibrium is dependent upon the product of the oxygen and carbon concentration of the metal. When the metal solidifies, the conditions so change that ferrous oxide and carbon react to form and evolve carbon monoxide.

Chuiko's data for 1485° C. (liquid iron), based on the observations of Chipman and Samarin, are given in Table 6. Here m_1 is a constant equal to the product of the carbon and oxygen concentrations in equilibrium with CO at atmospheric pressure.

If we are to prevent the formation of gas pockets, either as bubbles or entrapped in porosity, then we must maintain a pressure on the gas (over and above what surface tension may require) sufficiently high to prevent the evolution of gas; that is, we must maintain upon any gas which may have been momentarily evolved a pressure higher than the equilibrium pressures which we have just been discussing. It is fortunate that there is some solubility of gas in metal because if this were not so, then no pressure would be sufficient to reduce the voids to nothing by reducing their gas volume to nothing.

It is somewhat generally accepted in practical circles that oxidized metal is prone to shrinkage voids. Experiments intended to bring out an explanation in terms of contraction at the moment of freezing or coefficients of cubic expansion have, so far as the writer knows, been consistently unconvincing. It may, however, be that in this, as in many other matters, the observation of the practical man may have been perfectly reliable, but the explanation wrong. It may merely be that the over-oxidized metals contain enough gas-forming constituents to produce pressures sufficiently high to prevent feeding, while the others do not.

Table 6

PARTIAL PRESSURE OF CARBON MONOXIDE IN EQUILIBRIUM WITH VARIOUS CONCENTRATIONS OF THAT GAS IN MOLTEN IRON

(O), per cent	$(C)(O)$	$P_{(CO)} = \frac{(C)(O)}{m_1}$
0.010	0.0030	1.48 atm.
0.007	0.0021	1.04 atm.
0.006	0.0018	0.885 atm.
0.004	0.0012	0.590 atm.
0.002	0.0006	0.260 atm.

There is some analogy between the unsoundness due to gas and the unsoundness due to sonims. Both represent the inclusion of something else besides metal, which interrupts the continuity of the mass. In the case of sonims, these are solid nonmetallic substances, usually oxides or sulphides. They are not, as many seem to think, necessarily or even usually solid matter entrapped in the metal, but much more commonly they are chemical compounds which crystallize out of the liquid metal while the latter is cooling from the pouring temperature to the freezing temperature. Their formation depends upon the temperature-solubility relations of the liquid metal (solvent) and the chemical compound (solute). These solubility relations will differ with chemical composition and will not be capable of general discussion. Substances which separate as solid crystals or liquid drops immiscible with the parent liquid at temperatures above the freezing point of the metal have some ability to rise through the liquid metal and become part of any covering slag layer. The speed with which they can be eliminated depends on the particle size, the difference in density between the liquid metal and the solid or liquid inclusion, and the viscosity of the liquid metal, following what is known as "Stoke's law." We need not pursue the statement of this law further, but may point out that when the particles are very small, truly enormous time may be required for them to rise to the surface.

If the sonim does not separate from the parent liquid until metal crystals have begun to grow, it may readily be trapped among these crystals and never get out. If it is solid when trapped, it will take the form of angular or spherical solid masses embedded in the filler material of the frozen metal. If its melting point

is lower than that of the metal, it may be squeezed into thin sheets at the boundaries of dendritic crystallites. The pioneer work on this subject, in the case of steel, was done by Sims and Lillieqvist.

Feeding Castings

In considering the flow of liquid metal into voids which require filling up, we have so far tacitly assumed that the pressure exerted by whatever the atmosphere may be is the same at the surface of the liquid metal in the reservoir from which it is to flow, and on the liquid metal at the spot to which it is to go. This is not necessarily true; for example, a blind feeder may develop a completely frozen shell rigid enough to prevent atmospheric pressure from having any effect. Such a feeder can not supply liquid metal to a place in which atmospheric pressure exists unless the intervening column of liquid is so high as to balance the atmospheric pressure and leave something over to cause flow. The liquid will be sustained in the feeder and passage to the casting by the same principle which sustains the mercury in a barometer tube at a height corresponding to atmospheric pressure. Steps must be taken to see that atmospheric pressure can be maintained upon the surface of the liquid metal in the feeder, for ordinarily it would be quite impracticable to use so high a column of liquid metal as would permit feeding in spite of the existence of the so-called "Torricellian vacuum."

Inventors have devised means of causing the void in the feeder to be at atmospheric pressure, either by establishing communications permanently with the outside atmosphere or by causing evolution of a gas in the upper part of such a feeder. If there is no venting, then a feeder may even suck metal from a casting just as the chemist sucks a liquid into a pipette. On the other hand, if the process is reversed and a vacuum maintained within the frozen shell of a casting, then that casting may feed from a supply of liquid metal whose surface is below the place being fed, again on the pipette principle.

The improved solidity resulting from centrifugal casting is produced by the greater pressure of the liquid metal more readily overcoming the resistance to flow caused by viscosity or surface tension.

It can be shown that the static head H required to produce the same pressure as exists at a point R_2 away from the axis of rotation, if the free surface of the spinning metal is R_1 from the axis, is given by the equation

$$H = \frac{2\pi^2 n^2 (R_2^2 - R_1^2)}{g}$$

where n is the number of revolutions per second and g the acceleration of gravity.

Since a conductor carrying current will tend to move if placed in a magnetic field, such an arrangement can be used to apparently increase the density of a liquid metal carrying current and subject to such a field. A conductor of unit length, carrying unit current in unit magnetic field, the direction of which is at right angles to the direction of the current, has exerted on it unit force in a direction at right angles to both. The process is said to be applicable to the casting of dental inlays. It may be well to record that the pressure (c.g.s. electro-magnetic units) at a distance S below the surface is

$$P_1 = 2\pi S(2h - S) I^2/kwh^2$$

where h is the total height of the liquid metal, I the current it carries (horizontally), w the width of the rectangular conductor and k the outside width of non-magnetic refractory containing the metal, the whole channel being imbedded in a highly magnetic material. The magnetic field is that induced by the current.

Creep of Metal During Freezing

While we are thinking about the effect of pressure on the liquid metal within a casting, we must bear in mind that at least in the earlier stages of freezing the solid metallic shell is quite plastic. Internal pressure will, therefore, cause it to stretch, thereby altering the external dimensions of the casting made from a given pattern, with a corresponding effect on the amount of shrinkage void which may have to be filled in, or better, the amount of liquid metal which may have to be fed to the casting. No very direct experiments exist covering this point. However, Briggs and Gezelius experimented with the change in length produced when the contraction of straight steel specimens was retarded by making them deflect springs of various degrees of stiffness in the process of solidification and cooling. The bar restrained by the stiffest spring, turned out as one might expect, to be the longest. We may conceive that this increase in length represents the degree of creep which the solid shell underwent in the time required for passing through various temperature intervals. That is to say, we may conceive of a bar in any given instant, shrinking as much as it wants to by virtue of its thermal properties but during the same instant, being stretched by an amount depending on the load on the spring at that particular moment, and the creep rate of the steel. The actual results are probably of no precision, but Fig. 33, taken from Briggs and Gezelius, indicates the principle upon which these creep rates might be calculated graphically. In this figure there are a number of individual groups of curves. Those numbered 1, 2 and 3 are graphic representations of the relation between temperature and percentage of stretch (determined by deducting from the contraction of an unrestrained bar the contraction of a bar held by a particular spring), the time (based on a private communication from Briggs), and the stress determined from the deflection of the spring; that is, from the contraction of the bar. The curves marked E, G and C in Groups 1 and 3, and later on in 4, refer to three springs of three different stiffnesses employed by these investigators. The curves of Group 4 are determined by combining the information in Groups 1 and 2. The slope of the lines in Group 4 at chosen temperatures is then determined (by drawing a tangent), and this slope plotted against load in Group 5. Group 5-A is merely a reproduction of Group 5. We may then choose certain rates of stretch (1 per cent per minute) on each of the three curves and determine at what combinations of load and temperature these rates will occur. The dotted lines in Fig. 33 are the result of such graphic analysis. The sequence of the graphic process is illustrated by the dotted lines of Fig. 33. Starting at any point on the Curve 2, we project to the left until we intersect one of the curves of Group 1, here that for spring G. We also project to the right until we intersect the corresponding curve in

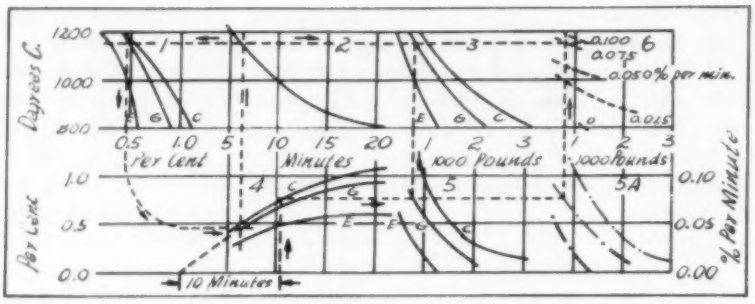


Fig. 33—Relation of Creep Rate at High Temperatures to Restrained Shrinkage of Steel Castings. (Data of Briggs and Gezelius. Analyzed by the Author.)

Group 3, and still further to the right as may be required later. From the intersection of our projecting line with G in Group 1, we project downward, turn 90° and project to the right into Group 4, by the familiar process of obtaining a V projection from H and P projections in descriptive geometry. The intersection of the horizontal projecting line in Group 4, with a vertical line from the starting point, gives us a point on Curve G. At this point we draw a tangent intersecting the line of zero elongation. We lay off a convenient time distance, here 10 minutes, on the X axis, and erect a perpendicular intersecting the tangent. From this intersection we project to the right in Group 5 until we meet the vertical projecting line coming down from Group 3, where it begins at the intersection of the original line with the G curve. This gives us one point in time which correlates the rate of stretch with the load for each of the three springs.

For convenience, we transfer Group 5 to 5-A and project upward from the point which has been found on the curve G into Group 6 until we intersect the original projecting line. This gives us the combination of temperature and load which corresponds to the rate of stretch measured by the horizontal projecting line which starts from Group 4 to Groups 5 and 5-A, and an indefinite number of repetitions will produce as complete a figure of the type required for Group 6 as may be needed. The construction is obviously complicated and it is quite possible that the graphic solution is not sufficiently accurate to be of much practical service.

The discussion is included here in order to emphasize the effect of restraint which might be, by internal pressure, in the contraction of a casting.

Experiments by Flagle and Chapman, under the author's direction, on the rate of stretch of white cast iron bars maintained under a constant load at elevated temperatures from 650° C. to 850° C. have shown that if the total time to reach rupture and the total elongation after rupture are each taken as 100 per cent, then

$$E = 0.45T + 0.000055T^3$$

Here E is the per cent of the total elongation which has taken place in T per cent of the total time. The relation is nearly independent of temperature or load, provided the latter exceeds a certain minimum as indicated immediately below.

It was also observed that the initial rate of stretch $\frac{dL}{Ldt}$ could be represented as a function of applied stress, S (psi), in terms of two consonants α and β by the relation.

$$\frac{dL}{Ldt} = \alpha(S - \beta)$$

These constants have the values shown in Table 7.

It may perhaps be logically urged that the solidification of metals as an abstract problem in physics need not concern itself very much with freezing rates or with the effect of environment upon such rates. The practical foundryman, however, being interested ultimately in the question of directional or progressive solidification, and other similar concrete matters, will not be content with ignoring the question of how rapidly solid metal will be deposited upon the walls of his mold. If he is to feed castings adequately, then he must see to it, by entirely practical methods, that solidification proceeds in such a way as to be first complete at the points removed from his feeders, and that solidification of the casting as a whole goes on progressively toward these feeders.

Thickness of Frozen Layer

The transfer of heat within various systems has engrossed physicists since the time of the French Revolution. Books have been written on this subject alone, and heat conduction forms a part of many treatises on physics. It would be practically impossible, under the circumstances for which this paper is prepared, to develop this subject adequately. A better and more useful approach is to quote liberally from the existing texts. As a matter of convenience for today's purpose, the quotations will all be from MATHEMATICAL THEORIES OF HEAT CONDUCTION, by Ingersoll and Zobel, Ginn and Company, 1913.

If the surface of the liquid be suddenly lowered to some temperature θ_0, which is below the freezing point of the liquid, and kept there, it is possible to find the thickness ε of solid metal which has formed in a given time T. Ingersoll and Zobel, page 151 (13) show that

$$\varepsilon = \alpha\sqrt{t}$$

but it still remains to determine the value of α.
They show, page 152 (20), that

$$\frac{k_1 C_1 e^{\left(\frac{-\alpha^2}{4h_1^2}\right)}}{h_1\theta\left(\frac{\alpha}{2h_1}\right)} + \frac{k_2 C_2 e^{\left(\frac{-\alpha^2}{4h_2^2}\right)}}{h_2\left[1 - \theta\left(\frac{\alpha}{2h_2}\right)\right]} = -L\rho\alpha\frac{\sqrt{\pi}}{2}$$

Table 7

CONSTANTS FOR DETERMINING INITIAL RATE OF STRETCH

Temperature	α	β
650° C.	0.000010 in/hour	15,500 psi.
700° C.	0.000009 in/hour	6,000 psi.
800° C.	0.000028 in/hour	3,500 psi.

This can be solved for α graphically by plotting the left side of the equation as a function of α, and the right side of the equation as a function of α, and seeing at what value the two curves intersect. We still have a variety of constants in the left half of the equation which we must define. These are k_1 and h_1^2, which represent respectively the conductivity and diffusivity of the solid substance, and the corresponding constants with the subscript 2 which represent the appropriate constants for the liquid substance. The expression

$$\theta\left(\frac{\alpha}{2h_1}\right)$$

means the value of the expression

$$\frac{2}{\sqrt{\pi}}\int_0^{\frac{\alpha}{2h_1}} e^{-\beta^2}\,d\beta$$

The latter expression can be found from probability integral tables. Time in this calculation counts from the moment when the first infinitesimally thin frozen layer appears. C_2 is the amount by which the temperature of the liquid substance exceeds the melting point when T is equal to O; L is the latent heat of fusion of the substances and ρ is the density of the substance taken alike in the solid and liquid, even though this is not precisely accurate. C_1 is a negative quantity corresponding to the difference between the constant's surface temperature and the melting point. It is also possible to determine the temperatures at various distances below the exposed surface of the solid. If x is the distance below the surface and θ_1 and θ_2 are the temperatures at distance x below the surface, the choice depending upon whether at that distance we find ourselves in the solid or liquid metal, and if T is the time measuring from the instant when the first solid appeared, then the authors show on Page 151 (11) and (12) that

$$\theta_1 = A_1 + B_1\,\theta\left(\frac{X}{2h_2\sqrt{t}}\right)$$

$$\theta_2 = A_2 + B_2\,\theta\left(\frac{X}{2h_2\sqrt{t}}\right)$$

and

Here $A_1 = C_1$ (In the preceding)

$$A_1 + B_1\,\theta\left(\frac{a}{2h_1}\right) = 0$$

$$A_2 + B_2\,\theta\left(\frac{a}{2h_2}\right) = 0$$

$A_2 + B_2 = C_2$ (In the preceding)

Since we have been able to determine α, the four equations above give us two equations for A_1 and B_1 and two others for A_2 and B_2, so that it is possible to evaluate the A's and the B's. We thus have sufficient information to determine the thickness of the frozen layer and the temperature distribution in terms of distances below the surface, all in terms of time, if we know the initial temperature of the liquid, the temperature to which the surface is suddenly cooled and the conductivity, diffusivity, density, and latent heat of fusion of the substances under consideration. The problem looks somewhat formidable, but is really only tedious. It can be executed by anyone with a knowledge of algebra and the skill to look up values in the probability integral tables. A possible stumbling block is the fact that the conductivity of a liquid is not especially easily determined or realized in practice. Few liquids will remain still under the conditions we are considering where convection currents are at once set up by differences of temperature.

This solution was first worked out by Neumann in connection with the freezing rate of polar ice. It is well to remember clearly what this condition implies. The freezing substance is supposed to be a "semi-infinite" body; that is, a body with a flat upper surface extending indefinitely in all directions, and the body is supposed to extend indefinitely far at right angles to the surface. Such a solution as Neumann's could not be applied to the complete freezing of such a body, for then there would come a time when the warmest part of the liquid was no longer at the original temperature C_2. Steffan worked on the same problem, making the assumption that the liquid was and remained at one temperature. The only temperature that would fulfill this condition is the freezing point. Under these conditions he found in Ingersoll and Zobel, op. cit., page 155, equation 39

$$\varepsilon^2 = \frac{2C_1c_1h_1^2\,t}{L}$$

where c_1 is the specific heat, which is identical with the Neumann solution if $C_2 = 0$. The expression does not give imaginary values for ε because C_1 is itself a negative quantity. Steffan's solution does not demand that the body extend infinitely at right angles to its surface. The considerations applicable to a thin frozen layer, in which the gradient may be supposed constant from the freezing point on the inside to C_1 on the outside also lead to the expressions in which ε^2 is proportional to time. None of our equations are good for anything but a flat boundary of indefinite area for the surface of the freezing substance. If we are concerned with the surface of a prism, cylinder or sphere, mathematical calculations become very complex. It has, however, been definitely shown by Chvorinov, in Fig. 34, that on an experimental basis the time for complete solidification of a steel solid, regardless of its geometric form, is proportional to the square of its ratio of volume to surface area. The individual points in Fig. 34 represent the times for complete freezing of a great variety of castings of simple form, ranging in size from a plate 10 mm. (0.4 in.) thick to a casting weighing 65 tons. The time for complete freezing ranges from one minute to 27 hours. If Chvorinov's data are correct, regardless of the shape of the casting, there is an implication that heat transfer in the metal is indefinitely fast compared with heat loss from the surface. Otherwise the freezing time of a heavy section would not be influenced by the contribution to mass and surface of an adjacent light section.

It seems that under practical working conditions, castings in sand molds freeze at the rates predicted, on the basis that time is proportional to the square of the distance solidified and that the temperature of contact between the metal and sand remains substantially constant. Briggs and Gezelius have furnished support for the latter assumption in Fig. 35. Their temperature measurements, taken at the center of a 9-in. sphere, at a distance of 2¼ in. from the center, and at the mold metal interface, indicate that the interface temperature is somewhat nearly con-

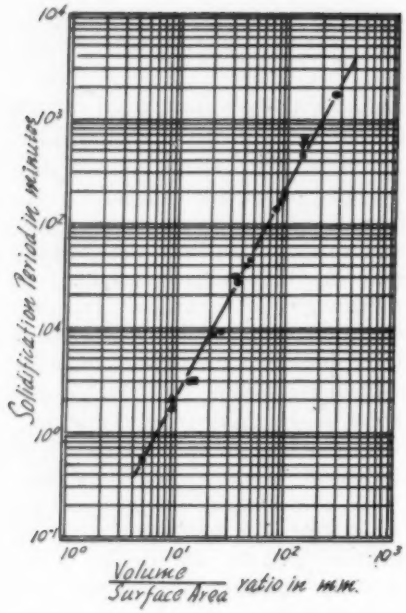


Fig. 34—Freezing Time of a Steel Casting as a Function of the Relation of Surface to Volume. (Chvorinov.)

stant from the beginning of freezing until even the center of the sphere has completely frozen. The temperature is exactly constant for a considerable portion of this time, and differs relatively little at the beginning and end of this period. Here, as in so many other cases, it is perhaps better to accept a simple reasonably close approximation than to attempt greater accuracy at the expense of complications.

Briggs and Gezelius finally interpreted their data for Fig. 36 in the form of an equation

$$D = K_1 t^{0.4} + K_2 t$$

where D is the thic' ness of the frozen layer, in inches, t the time in minutes and K_1 and K_2 constants depending upon the dimensions and form of the freezing object. For spheres these constants are as given in Table 8.

Table 8

CONSTANTS FOR BRIGGS' AND GEZELIUS' EQUATION

Diameter	K_1	K_2
9 in.	0.342	0.125
6 in.	0.346	0.172
3 in.	0.309	0.428

Although these parameters give lines agreeing well with the observations, they all depart in the direction of longer time from the observations as freezing approaches completion.

It is instructive to compare their observations with Chvorinov's, whose data implied that

$$T = 0.02 \left(\frac{V}{A}\right)^2 \text{ (in minutes and millimeters)}$$

where T is the time for complete freezing in minutes, and V and A are the volume and area of the test body in mm units. For a 9-in. sphere, $\frac{V}{A} = \frac{1}{3} r = 1.5$ in. $= 38$ mm. and $T = 0.02 \times 38^2 = 29$ min. (approximately). At 29 min. the Naval Research Laboratory would have formed a layer almost 5 in. thick, i.e., it froze in somewhat less than 29 min. The relation $T = 0.016 \left(\frac{V}{A}\right)^2$ represents their extrapolated freezing times quite well. The difference in interface temperatures 2575° F. for Chvorinov and 2300° F. for Briggs and Gezelius, should have made the difference in the reverse direction.

The writer has re-plotted these data for all spheres upon a single sheet, using as the unit of time, the time for complete freezing, calculated from the latter expression and as the unit of length the radius of the sphere. Provided as much as 0.18 times the radius has frozen, the points fall rather well on a straight line joining 0.1 at zero time with 1.0 at the freezing time. At the beginning of freezing the process is slower than required by the rectilinear relation. Since one is usually not so much interested in the initial stages of freezing, the relation

$$\frac{D}{R} = 0.1 + 0.9 \frac{T}{T_0}$$

where T_0 is the freezing time, may be convenient.

Can it be that the constancy exists in the early stages of freezing but not later, so that extrapolation of

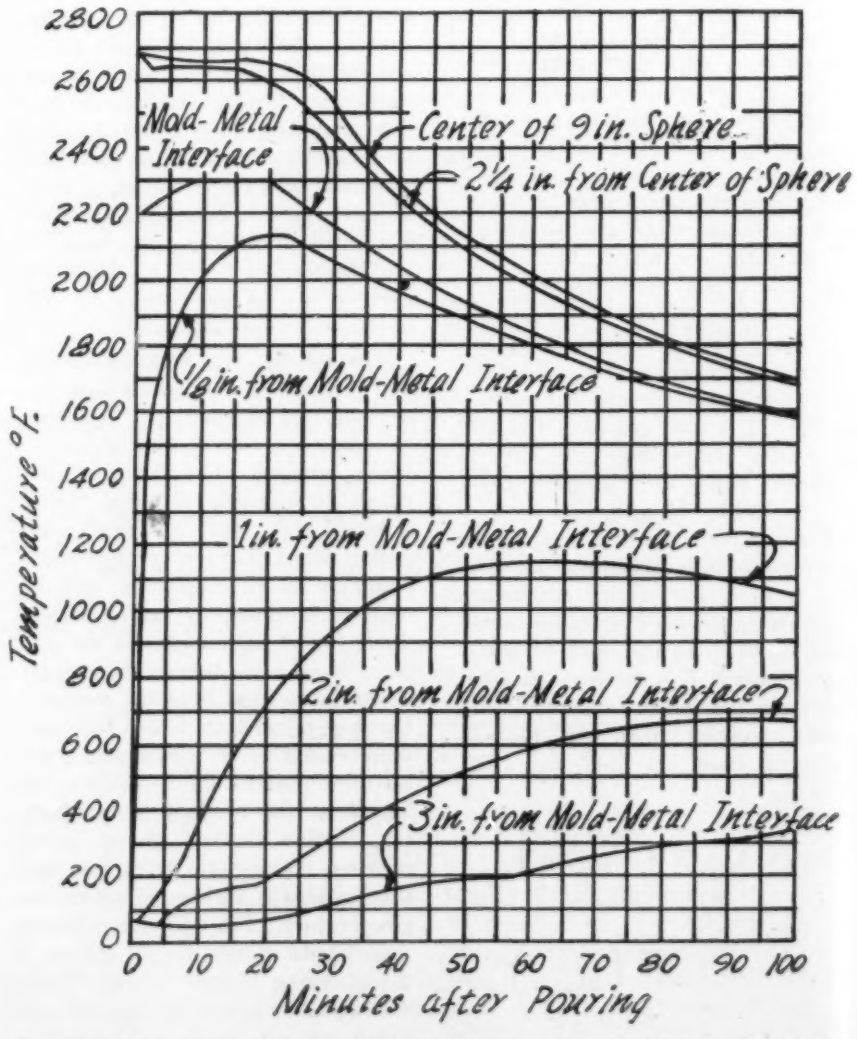

Mold-Metal Interface
Center of 9 in. Sphere
2¼ in. from Center of Sphere
½ in. from Mold-Metal Interface
1 in. from Mold-Metal Interface
2 in. from Mold-Metal Interface
3 in. from Mold-Metal Interface
Temperature °F.
Minutes after Pouring

Fig. 35—Relation of Temperature to Time When Casting a 9-In. Steel Sphere. (Briggs and Gezelius.)

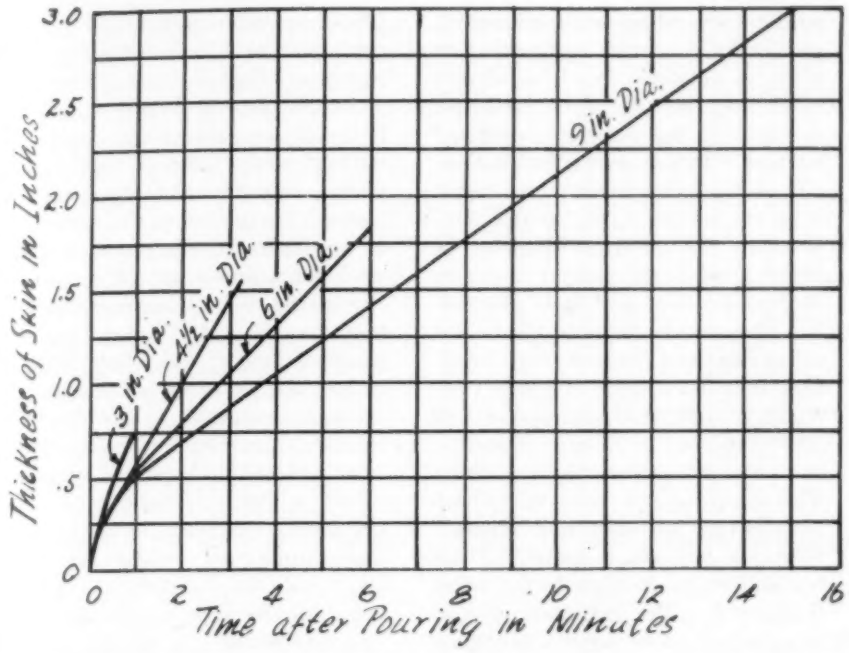


Fig. 36—Rate of Skin Formation in Steel Spheres Cast in Dry Sand. (Briggs and Gezelius.)

the time of complete freezing can not be justified?

An apparent discrepancy between Briggs and Gezelius and Chvorinov is found in certain data of the former relating to the freezing of rectangular prisms, all having the volume of a 6-in. sphere but areas 1.35, 1.60 and 2.10 times its area. Chvorinov's ideas would require that the freezing time be inversely as the squares of these numbers, i.e., 0.55, 0.37 and 0.23 times the time for freezing the sphere. Actually the rate of freezing (inches per minute) was identical in all cases so that the extrapolated freezing times were inversely as the minimum dimensions or 0.6, 0.37 and 0.23 if the thickness frozen were a linear function of time throughout, or 0.65, 0.41 and 0.18, making allowance for the curvature of the beginning. Apparently, therefore, the predictions are similar, at least by either set of data, and the experiments are not sufficient to point unequivocally to the most reliable theoretical explanation.

The major discrepancy remaining is that the result on spheres showed the amount of metal deposited, per unit area of surface to be a curvalinear and not a rectilinear function of time. This curvature is, however, supported by Troy's data and by unpublished observations by Yearly at the Chicago Works of the National Malleable and Steel Castings Company.

Briggs and Gezelius' summarizing the relation of the volume of metal frozen per cubic inch in relation to time, as in Fig. 37, without regard to the geometric form of the specimen cannot be correct. When a sphere has completely frozen the volume of solid metal per unit area of surface is 1/3 the radius

$$(\frac{4}{3}\pi R^3 \div 4\pi R^2).$$

For a 9-in. sphere this is 1½ cu. in.; for a 6-in. sphere, 1 cu. in.; for a 4½-in. sphere, 0.75 cu. in.; and for a 3-in. sphere, 0.5 cu. in. The corresponding freezing time from these summaries are 6-in. sphere, 6 min.; 4½-in. sphere, 3½ min.; 3-in. sphere, 1½ min. However, their own data show that at 6 min. the 6-in. sphere has a frozen shell 1.8 in. thick; the shell of the 4½-in. sphere

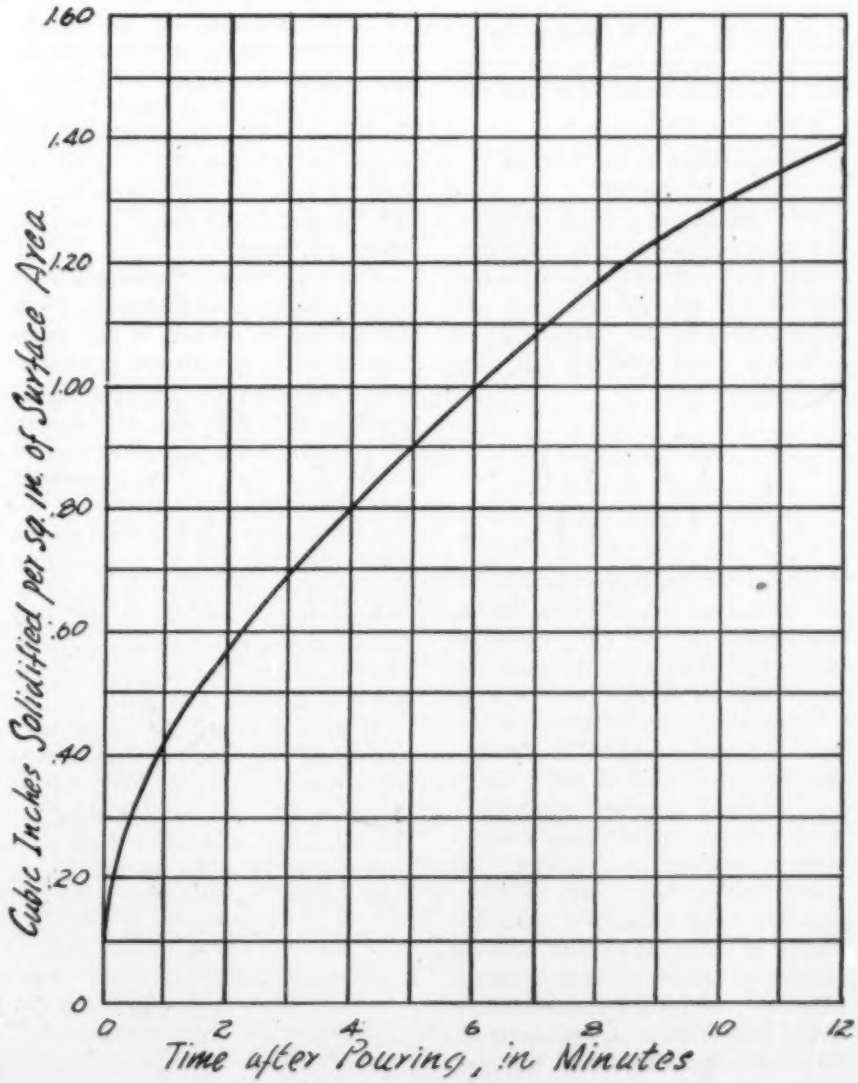


Fig. 37—Rate of Solidification of Steel Nearly Independent of Form or Size of Specimen. (Briggs and Gezelius.)

is 1.6 in. thick at 3½ min.; and that of the 3-in. sphere about 1 in. thick at 1½ min. Evidently their graph errs greatly in the direction of too short a time for small spheres and a more complicated relation is unavoidable.

The progress of incomplete freezing in the spheres cast at the Naval Research Laboratory can be expressed fairly well by some such equations as

$$\frac{T}{R^2} = 0.345 \left(\frac{D}{R}\right)^2$$

$$\text{up to } \frac{T}{R^2} = 0.128$$

and

$$\frac{D}{R} = 0.06412 + 0.8548 \left(\frac{T}{R^2}\right)$$

$$\text{above } \frac{T}{R^2} = 0.128$$

where D is the thickness of the frozen layer at time T for a sphere of radius R in inch, minute units. Evidently only in the former equation is D independent of R and dependent only on T.

Temperature at the Surface of Contact

The instantaneous temperature at the surface of contact is calculable for two semi-infinite solids of known, but different thermal properties and temperatures by the equation given by Ingersoll and Zobel, op. cit., page 80, equation 49,

$$\theta_0 = \frac{\left(\frac{k_1\theta_1}{h_1} + \frac{k_2\theta_2}{h_2}\right)}{\left(\frac{k_1}{h_1} + \frac{k_2}{h_2}\right)}$$

If one of the bodies is a liquid and the conditions are such that the instantaneous surface temperature is below the melting point, then the latent heat of fusion must be considered, although the above equation does not recognize it. Perhaps the simplest method of doing this is by a series of successive approximations. Assume some instantaneous surface temperature. Divide the latent heat of fusion over the temperature range between θ_1 and this estimated temperature and add the amount to the specific heat c_1 of the substance, computing an assumed h_1. Using this value of h_1, compute θ_0. Generally speaking, this will not come out the assumed value. Use the first approximation of θ_0 in computing a second approximation of h_1 and hence a second approximation of θ_0. A relatively few trials should result in no further significant changes in θ_0. Another suggested method is to give to the liquid body a fictitiously high temperature calculated by adding to its actual temperature the quotient obtained by dividing the latent heat of fusion by the specific heat and then proceeding directly as before. Chvorinov calculated and proved experimentally that the surface of contact between a sand mold and liquid steel was very near 1450° C. regardless of minor variations in conditions. This result agrees only fairly well with Briggs and Gezelius' observations, for 1450° C. is about 2575° F. Some calculations made by the writer indicate that the instantaneous surface temperature at the boundary between a steel casting and a steel chill should be approximately 950° C. Saito calculated that the surface of contact between an ingot and an ingot mold for ingots 160 cm. in diameter, poured at 1600° C. into molds at 0° C. should remain between 850° C. and 870° C. after the first 15 min. for some three hours. The ingot should have frozen in about 2½ hours.

The temperature distribution with respect to time and to distance from the surface of contact of two semi-infinite solids of different properties and temperatures presents great mathematical difficulty. If the substances are alike, the solutions are relatively simple. That simplified case, however, is of no consequence for our purpose. It has been shown mathematically that the temperature of the surface of contact of two semi-infinite bodies initially at different temperatures, does not change with time, whether the two are of the same or different materials.

If θ_1 and θ_2 are the initial temperatures, h_1^2 and h_2^2 the initial diffusivities and θ_m the temperature at the surface of contact then, for various values of x and t when positive values of x are in material 1 and negative in material 2

$$\theta = \theta_m - (\theta_m - \theta_1)\frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2h\sqrt{t}}} e^{-\beta^2}\,d\beta \qquad \text{(x positive)}$$

$$\theta = \theta_m + (\theta_2 - \theta_m)\frac{2}{\pi}\int_0^{\frac{x}{2h\sqrt{t}}} e^{-\beta^2}\,d\beta \qquad \text{(x negative)}$$

These equations are not, however, applicable to a body whose state is changing. Except by such experiments as those of Briggs and Gezelius, we are, therefore, unable to judge of what change of temperature occurs with time at the boundary surface. In any event the restriction to semi-infinite solids would make any computation of little interest. Eventually the temperature of the boundary of a solid losing heat, determines in part, how fast the heat is lost. It has been shown that if the temperature C_1 in the Neumann solution, discussed some pages back, falls sufficiently rapidly, ϵ can be made a linear function of time. Obviously, therefore, in principle at least, almost any relation of ϵ and time could be produced by establishing a suitable time temperature relation at the surface of the freezing substance. As foundrymen we are, however, interested only in those relationships which can be brought about under the conditions existing in the freezing of metal in a mold.

The observation that the thickness of metal deposited varies as the square of the time, suggests the desirability of studying freezing rates on the supposition that the freezing conditions are sufficiently nearly approximated in practical cases if we assume that the surface of the cooling casting is at constant temperature until the casting is completely solidified. The earlier discussion of the relation of Chvorinov and Briggs and Gezelius data of course does not support this assumption. It would be nice also if the surface temperature could be taken as that calculated for the instantaneously reached temperature at the surface of contact of the casting and mold. In the earlier stages of freezing we might also find it admissible to assume that the average temperature of the liquid and the average temperature of the solid are the same while freezing is going on, although of course these two temperatures are different from each other.

We cannot readily adapt our mathematics to the treatment of any-

thing but the flow of heat in one direction. We can, therefore, study only the rate of freezing of plates whose extent is very great in length and breadth as compared with their thickness. The rate of heat loss from such a plate should be calculable from the thermal properties of the mold material and from the temperature of the surface of contact which, remember, is supposed to be constant. It is shown by Ingersoll and Zobel, op. cit., page 78, equation 38, that:

$$\theta = \frac{2\theta_o}{\sqrt{\pi}} \int_{\frac{x}{2h\sqrt{t}}}^{\infty} e^{-\beta^2}\, d\beta$$

Where θ is the temperature at distance x below the surface of the semi-infinite body (for example, the sand in the mold), in time t after the mold has been filled, if the constant surface temperature is θ_o, both θ and θ_o being measured above the initial temperature of the mold. If we choose to consider not a sand body so thick that its back surface does not heat during the freezing of the metal, but prefer to talk about a chill of finite thickness, then it is shown by Ingersoll and Zobel, op. cit., page 108, equation 128, that

$$\theta_1 = \theta_o \left\{ 1 - \frac{2}{l} \sum_{m=1}^{m=\infty} e^{\frac{-h^2 m^2 \pi^2 t}{l^2}} \cdot \sin \frac{m\pi x}{l} \int_0^1 \sin \frac{m\pi\lambda}{l}\, d\lambda \right\}$$

where l is *twice* the thickness of the slab and m is a whole number. In either case one may obtain the value of $\frac{d\theta}{dt}$, multiply this by k, the conductivity of the mold material, sand or metal as the case may be, to obtain a value of $\frac{dH}{dt}$, and integrate between the limits $t = 0$ and $t =$ any chosen amount for values of $x = 0$, in order to obtain the amount of heat which has been absorbed by the mold wall in the chosen time. Dividing this heat content by the heat given off when liquid metal is converted to solid metal at the temperature of the mold metal interface, the amount of metal deposited on the wall can be calculated.

The results are not always very satisfactory. In Fig. 38, we have represented the results of such calculations by solid lines and have shown by dotted lines certain observed values obtained by Troy. It will be seen that the data for sand

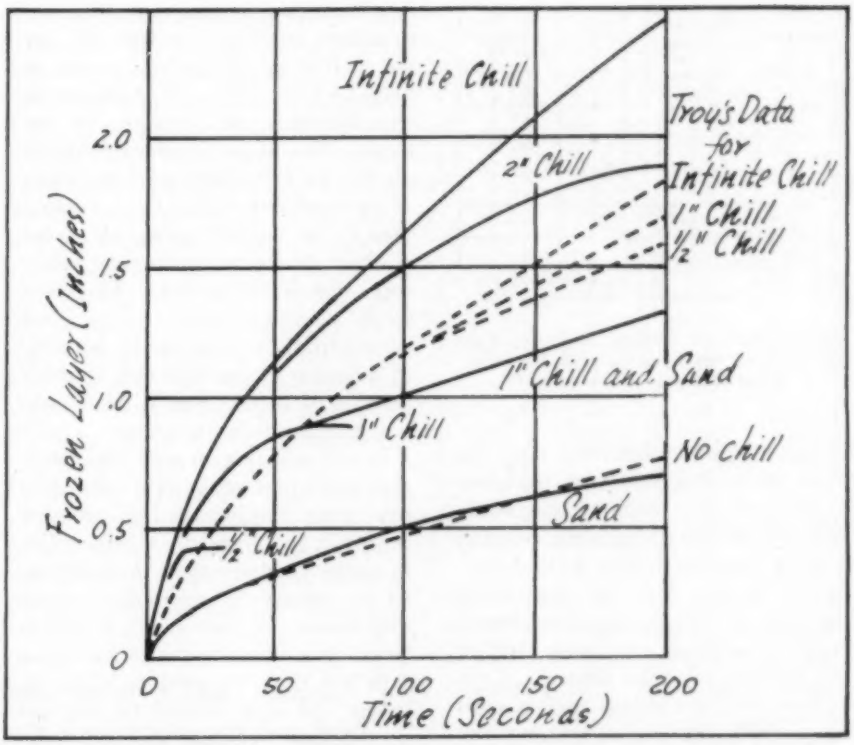


Fig. 38—Calculated and Observed Rates of Skin Formation in Sand Cast Steel Ingots.

molds agree, to all intents and purposes, precisely. However, the constant of proportionality between the time and the square of the thickness of the frozen layer is of an order of magnitude about twice that derived from the Briggs & Gezelius data. The data for indefinitely thick chills show that Troy's results are substantially about 0.7 of those calculated. This may well be due to an error in the assumption that the surface of contact of metal and mold retains the initial instantaneous temperature. More will be said about this shortly.

Alternatively, it may be that the temperature at the surface of a chill is not the same as that at the surface of the casting after the two have had time to separate slightly, due to shrinkage of the casting. The calculations for chills of finite thickness made on the assumption as above that no heat leaves the back surface of the chill, bears little or no resemblance to Troy's observations. A calculation made by attempting to take into account the heat lost from the back of the chill, gives a curve somewhat nearer the shape found by Troy, but not yet in satisfactory agreement. If we depress this curve in the ratio of 0.7 to 1 on the assumption that this is the error in our assumption of surface temperature, then our entire curve falls below Troy's observed curve, except perhaps in the first 25 seconds or so. Troy did not work with a slab of indefinite extent but with a block 5x5x8 in., against one face of which a chill 3 in. square was set. It is quite reasonable to suppose that Troy's chill lost heat not only from its rear surface but also from its edges, and that, therefore, it should have abstracted somewhat more heat than did ours. That it should have abstracted almost twice as much heat seems improbable and it is, therefore, apparently true that calculations based on this principle are applicable to sand molds if the surface temperature be calculated, and to indefinitely thick chills with a suitable correction of the calculated temperature but not to thinner chills. Troy's curve for "adequate" chills, which are chills which behave substantially like infinitely thick chills, correspond empirically to a constant surface temperature of about 1100° F. (595° C.). The condition indicated by Fig. 39, that in the beginning the freezing rate is not at all affected by the thickness

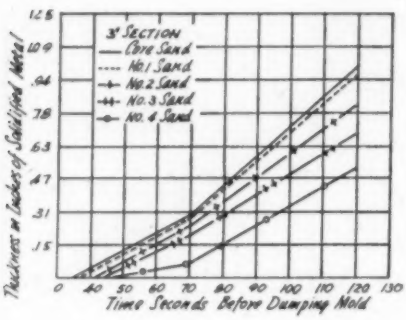


Fig. 39—Rate of Freezing of White Cast Iron in Sand Molds of Varying Properties. (Yearly, Shauss and Martin.)

of the applied chill, but that at times increasing with the thickness of the chill, that thickness does come into play in determining the freezing rate, is not only found in the computed cases, but is supported, through not so strongly, but considerable operating experience within the knowledge of the writer.

For steel cast either against sand or a chill, the curve relating the thickness of the frozen layer to time has nearly the expected form, a parabola with its vertex at the origin. This is not always true. For white cast iron poured into sand, loci have been found which do not pass through the origin and which are convex toward the time axis instead of concave. (See Fig. 39.)

The reason for the former is simple enough, the heat content of the liquid metal, above the relatively low temperature of complete solidification, is sufficient so that the temperature reached at the mold surface at the moment of contact is high enough so that solidification has not occurred and heat must be conducted into the mold before freezing can be seen to begin, which takes time. The same cast iron poured against a steel chill freezes at once and the rate of formation of the solid layer decreases with time.

The increase in rate of solidification with time implies corresponding increase in temperature gradient at the sand surface except to the extent that a decreasing area of contact of liquid and solid metal distorts the form of the locus. Thus when, in Fig. 39, 0.78 in. of metal has frozen, the liquid metal is in contact with the solid for a width of 1.44 in. instead of 3 in. At that time for core sand, about 0.07 in. of metal are deposited in 5 sec., or say 0.014 in. per sec., or about 0.02 cu. in. per in. of height. At the beginning 0.05 in. are deposited in 5 sec. or 0.01 in. per sec. or 0.03 cu. in. per sec. per in. of height. This represents a change in the direction of curvature of the locus. The figure incidentally gives an excellent illustration of the effect of permeability of sand on freezing rate. The "open" sands by virtue of their air spaces are poor conductors and freeze slowly. The core sand, though "open," has a good conductivity because of the bonding of adjacent grains by binder, which permits of conduction of heat without jumping over air spaces.

It is interesting to note that when the deposition of a solid skin does not begin instantaneously, freezing begins in geometrically similar solids in times approximately proportional to the squares of the solids' linear dimensions. A 3-in. prism began to freeze in a time interval about from 3 to 3½ times as great as a 1½-in. prism. (4 min. would be the expected time.) This is believed to be, in part, accounted for by measuring time from the moment when pouring was complete, and in part by the fact that the temperature of the liquid metal remains only approximately uniform throughout. The agreement is probably as good as could be expected under the conditions of shop experiment with the assumption that amount of sand to be heated before freezing begins is proportional to the amount of metal from which its heat is derived, and that the time for a given temperature to be attained in the sand is proportional to the square of the distance below the surface.

Mathematically, if two semi-infinite solids of the same material, but of different uniform temperatures, have their faces brought into contact, this contact surface should instantly take the mean temperature and should retain this temperature unchanged indefinitely. This problem is not exactly analogous to the pouring of a heavy iron casting against a heavy iron chill because it does not regard the latent heat of fusion of the substance, because of mathematical difficulties. Whether because of the omission of this contribution of the heat content, or because contact between the casting and chill is not necessarily maintained, experimental data do not confirm this approximation of a constant contact temperature very well. Figure 40 represents some measured interface temperatures as determined by C. H. Junge in the author's laboratory.

These data are offered, in part, to show what contradictions can occur. The surface temperature does not remain constant nor does it vary similarly for two thicknesses of chills. The surface temperature which is approached is not that which empirically satisfies Troy's observations, nor that which would be calculated from the initial conditions.

It is quite evident that heat transfer from a casting to a chill is more complex than can be expressed by any of our simplifications.

This information can be used in the computation of the amount of heat which a chill of infinite thickness will absorb. We have already seen, when quoting from Ingersoll and Zobel, on page 78, equation 39, what the relation of temperature to time and distance below the surface is in such a chill. The value of the coefficient of θ_0 in that equation is shown as a curved line in Fig. 41, whose coordinates are time as abscissa, and the value of the coefficient measured along a uniform scale as shown by the ordinate scale at the left of the diagram. The curve is computed for unit thickness of 1 cm. (If the material be iron, $h^2 = 0.173$). It is somewhat difficult to compare a curve which has been experimentally determined, with these data, for a laborious computation for many points in each of

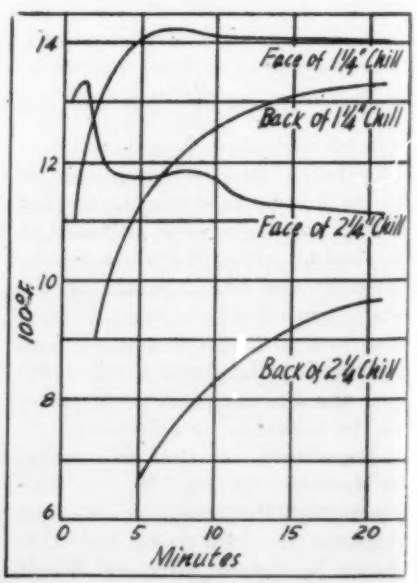


Fig. 40—Some Actual Chill Temperatures. (Junge in the Author's Laboratory.)

several thicknesses would be required. We can, however, by distorting the scale of the ordinate, convert the curve of this diagram into a straight line. This has been done for a straight line whose slope was arbitrarily chosen to represent unit distance below the surface. The appropriate non-uniform scale for the coefficient is shown in the ordinate scale at the right of the figure.

By taking advantage of the fact that the time to reach any chosen temperature at a given distance below the surface varies as the square of that distance, we can then at once rule in a series of straight lines, each representing a different thickness, thus greatly facilitating the evaluation of the diagram.

Figure 41 was chosen to show the application of the method rather than for practical application. The non-uniform ordinate scale widens out very rapidly until the value of unity for the coefficient is reached only at an infinite distance. In Fig. 42 we have shown a very similar diagram drawn to a different scale, choosing the latter so as to bring the values of the times and coefficients within the range most useful for the interpretation of Fig. 40. The dots on this diagram represent the observational data of one of the curves in Fig. 40. The ordinate for each observation was determined by dividing the observed temperature rise by the total temperature rise. It will be seen that the observed points can be fairly well represented by a straight line such as that shown dotted in the figure. Such a line by its slope will indicate the distance

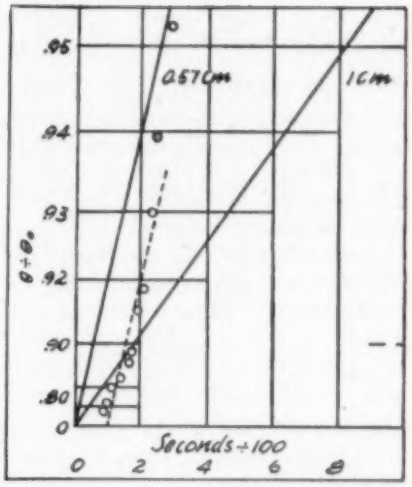


Fig. 42—Scheme for Correcting for Heating Rate of Chill Surface When Calculating Freezing Rates.

below the surface of a uniform chill, at which such a temperature time relation might be expected to occur.

The fact that the dotted line does not run through the origin suggests that the results can be empirically interpreted as representing the lapse of a small period of time before anything happens. The fact that the dotted line, instead of being straight, is actually concave upward, may be due to uncertainties arising from the opening out of the scale near the top, or may be an indication of a change in heat transfer from casting to chill as cooling goes on. We are thus in a position to say that the conditions at the surface of the actual chill are those which would be expected at a particular distance below the surface of a theoretical chill if the pouring had actually taken place a little later than it actually did. This is to say we substitute for the value of time in the equation, a new time obtained from that which was observed by subtracting an arbitrarily determined constant.

It is, of course, to be remembered that since it takes time to fill a mold, the selection of zero time is in any event somewhat vague. Having the temperature time relation of the surface of a real chill and considering it as a plane situated in an infinite chill at that distance below the surface which Fig. 40 requires, we can determine the rate of heat absorption by that part of the infinite chill more distant from the metal which has been poured than the predetermined distance below its surface. The mathematics for do-

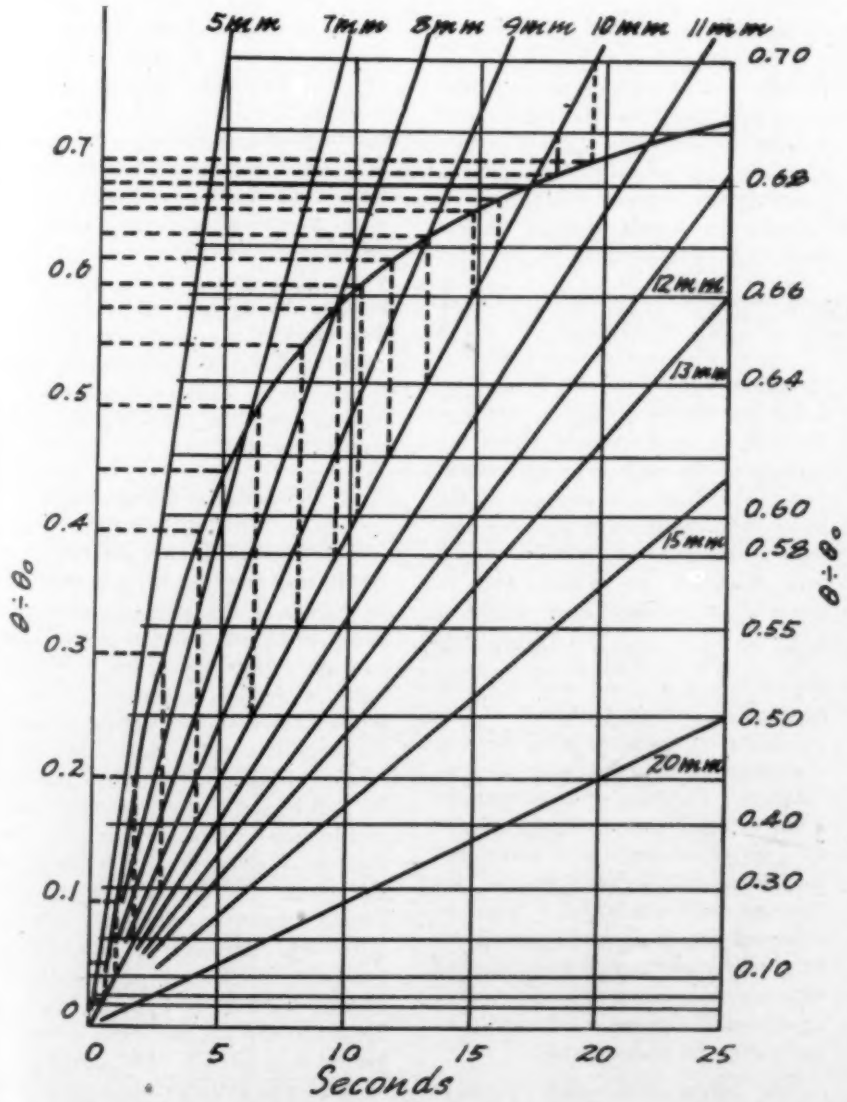


Fig. 41—Scheme for Simplifying the Representation of the Time Temperature Relation at Various Distances Within a Semi-Infinite Body by a Change of Scale.

ing this is rather simple, by differentiating Ingersoll's quoted equation 38 to obtain a value of $\frac{d\theta}{dT}$. Multiplying this value by the conductivity of the chill material give a value for $\frac{dH}{dT}$ which represents the rate of heat input into the chill.

Ingersoll and Zobel, page 79, equation 44, with a slight change in nomenclature, arrive at the result

$$\frac{dH}{dt} = \frac{k\theta_0}{h\sqrt{\pi t}} \frac{-x^2}{e^{4h^2t}}$$

which setting the values of h^2 and k for iron in the appropriate places, becomes

$$\frac{dH}{dt} = \frac{0.2\theta}{\sqrt{t}} \frac{-1.45x^2}{e^{t}}$$

with sufficient accuracy for our purpose.

Plainly the heat absorbed by that portion of an infinite chill lying more than distance x away from its exposed face in time t is

$$H = 0.2\theta \int_0^t \left(\frac{1}{t}\right)^{\frac{1}{2}} e^{\frac{-1.45x^2}{t}} dt$$

This integral can be represented by the rapidly converging series in

$$2t^{\frac{1}{2}} e^{\frac{-a}{t}} \left[1 + \frac{2a}{t} - \frac{4a^2}{3t^2} + \frac{8a^3}{15t^3} - \frac{16a^4}{105t^4} + \frac{32a^5}{945t^5} - \frac{64a^6}{10395t^6} - \cdots \right]$$

in which $a = 1.45^2$ for an iron chill. The x for the problem under discussion is that deduced from Fig. 41.

The preceding series, of which only a few terms need ordinarily be used, has other applications. For molding sand a in this expression has the value 51, with which alteration the series is applicable to that material.

The expression for the temperature within a semi-infinite body as a function of distance below the surface and time when the surface is suddenly raised and maintained at a given temperature above the initially uniform temperature of the body, shows on simple inspection that for different materials the time temperature relation is the same at distances proportional to the corresponding value of h.

When we come to consider the freezing of more complex objects, the mathematical treatment becomes prohibitively complicated. In the beginning the freezing of a round ingot, or indeed of a square one, can be treated as we did the freezing of a slab. However, as soon as the thickness of the frozen layer ceases to be negligibly small compared with the ingot's diameter, then heat no longer flows out in parallel paths perpendicular to the surface, but in radial paths, to which our earlier discussion is not adapted. Near the corners of a casting, heat is abstracted in at least two directions, so that freezing takes place more rapidly than at the middle of a flat side. The conversion of this qualitative statement to a quantitative formula when latent heat of fusion is also to be considered, cannot be attempted. The problem of a sphere of a given substance at a known temperature above its surroundings, immersed in an infinite mass of the same material, is solved by Ingersoll and Zobel, page 126, equation 13. It is, however, of little application to foundry problems.

J. B. Austin has discussed the application of a series of tables calculated by Russell for the Alloy Steel Research Committee. These tables give the temperature by which a point in an infinite slab, or in a cylinder of infinite length, differs from the temperature of the surroundings, which the whole mass of metal will finally attain; in terms of the rate of heat transfer across the surface of the object, its half thickness (or radius) the position of the point from the median plane or center expressed as a fraction of the half thickness or radius, and in terms of a relative time which is equal to $\frac{h^2}{l^2} t$, where l is the half thickness (or radius) and t is the time. The system of units is at first confusing but presents advantages in the direction of simplifying the calculation. The rate of heat transfer is an experimental constant specific to a given substance and given surroundings, but independent of the dimensions of the body. It must be obtained for each set of conditions by direct experiments by matching an observed heating or cooling curve against calculations made for various values of transfer rate.

The most interesting application of these principles is that they permit the calculation of the time temperature relation at a chosen point within a solid of any given reasonably simple form. For example, a point within a rectangular block, say 10 cm. × 20 cm. × 30 cm., which is 5 cm. below the surface in the direction of the 10-cm. dimension and 2 and 10 cm. in the other two, can be treated successively as 5 cm. below the surface in a 10-cm. slab, 2 cm. below the surface in a 20-cm. slab and 10 cm. in a 30-cm. slab. For each condition the fraction of the total temperature change which is not yet accomplished can be calculated and the actual fraction still remaining is the product of the three fractions. The treatment was developed in connection with the problems connected with the heat treatment of steel, but is equally applicable to our purposes. Its principal source of error is that there is no way to take into account latent heats of fusion (transformation in the case of steel heat treatments). Russell's tables are too voluminous for reproduction here but can be found in Austin's publication. Schwarz suggested treating the problem of an ingot freezing in a chill mold as a heat source and proposed taking account of the air space between the ingot and the mold wall by considering the fall of temperature through it and its conductivity. This neglects any contribution made to the heat transfer between the casting and mold wall by convection currents or radiation.

Difficulties in Computing Freezing Rates

There are also other difficulties in computing freezing rates in relation to directional freezing arising out of heat conduction parallel to the mold surface. Quite evidently if we imagine a vertical cylindrical casting whose lower portion is surrounded by a hollow cylindrical chill, and whose upper portion is surrounded by sand, and if we consider only conduction perpendicular to the castings surface from the metal to the mold, the chilled portion will freeze before the sand cast portion. This will produce a temperature gradient inside the partially frozen casting so that at a given distance from the surface the metal is colder below than above. The upper portion of the cylinder then cools not only by conducting heat radially outward, but also by conducting it

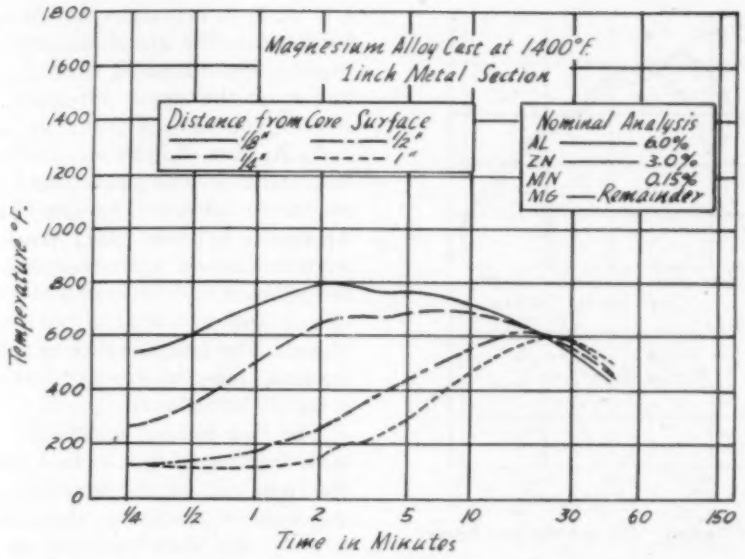


Fig. 43—Temperature Distribution in Core of a Magnesium Casting. (Chamberlin and Peters.)

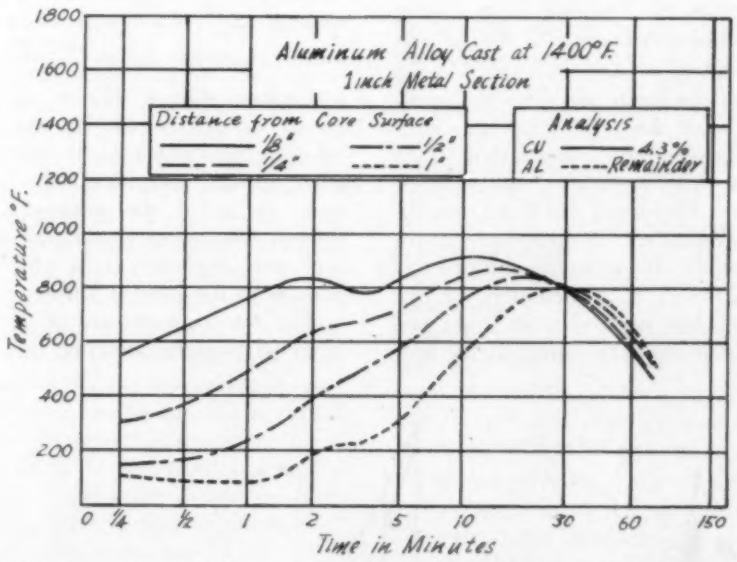


Fig. 44—Temperature Distribution in Core in an Aluminum Casting. (Chamberlin and Peters.)

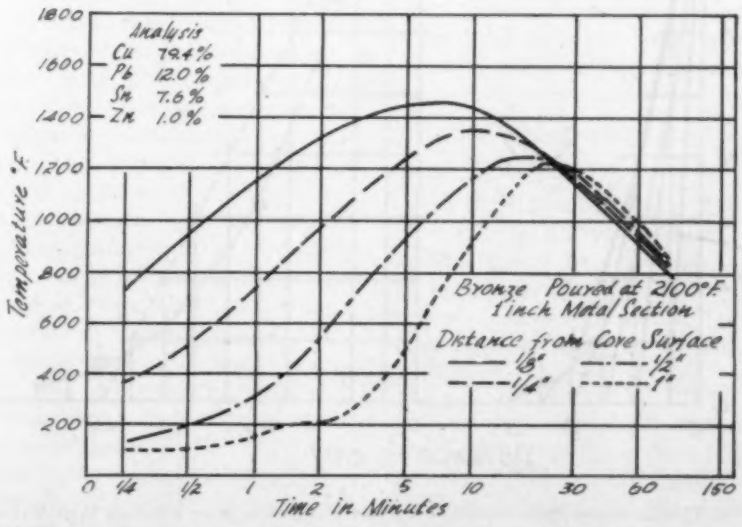


Fig. 45—Temperature Distribution in Core in a Bronze Casting. (Chamberlin and Peters.)

axially downward. The result is then that the upper part of the cylinder freezes more rapidly and the lower part less rapidly than would be predicted considering the two portions entirely separately. Furthermore, the chill loses some heat from its upper surface to the sand above it. This causes a slower absorption of heat into the sand from the upper part of the casting and thus slows down the freezing there while the reverse process accelerates the freezing of the chilled portion. Which of the two actions will be predominant is again a problem whose mathematical expression is beyond this writer's knowledge. An additional complication is the heating of sand by metal flowing past it. It is very plain that in such problems as this we are much handicapped by our inability to handle the mathematics involved. Even very simple conditions correspond to difficult or impossible mathematical operations. Further complications arise in computing the cooling rate of metal in a mold when the material of the latter contains combustible material such as core binders. The burning of such organic compounds generates heat within the mold and retards the cooling rate considerably. Chamberlin and Peters recorded instances when temperatures higher than the surface temperature were reached when heating cores in constant temperature furnaces. Some typical records of temperatures obtained by these workers within cores in castings are shown herewith, Figs. 43 to 46.

In the foundry one encounters few cases where liquid or solid metal loses heat by radiation from a bare surface. Perhaps it is convenient to have the facts recorded for reference. The Stephan-Boltzman equation states that the amount of heat radiated by a black body is proportional to the fourth power of the absolute temperature. The constant of proportionality is

$$13.73 \times 10^{-8} \text{ calories, cm.}^{-2} \text{ secs.}^{-1} \text{ deg.}^{-4}$$

That is to say that a black body radiates 13.73 calories per square centimeter per second multiplied by the fourth power of its absolute temperature.

"Black body" conditions are realized only in closed furnaces at uniform temperatures. Hot surfaces ex-

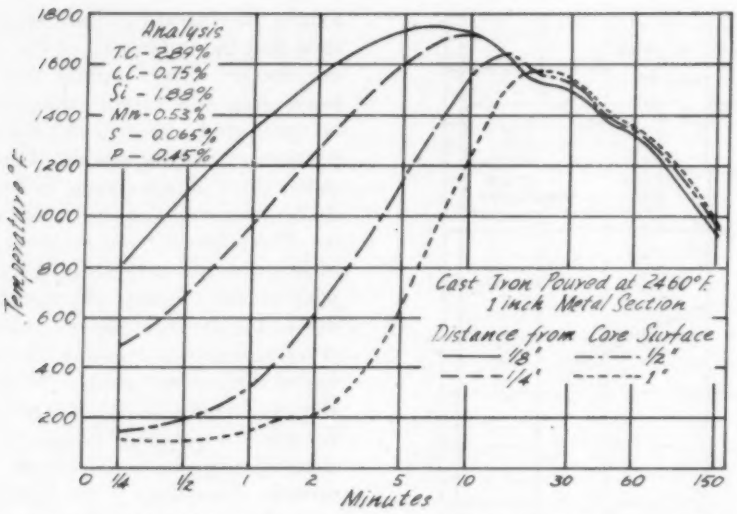


Fig. 46—Temperature Distribution in Core in an Iron Casting. (Chamberlin and Peters.)

posed to ordinary surroundings radiate less rapidly. Molten copper radiates only about 15 per cent as much energy as a black body, molten iron 27 per cent, iron oxide 88 per cent and copper oxide 83 per cent. In the unusual case when heat radiation is to be considered, these data may suffice for heat loss calculations.

Sherwood and Reed describe in detail a graphic method invented by Schmidt for plotting temperature distributions for linear heat flow in the "unsteady state," i.e., when given points in the heat conducting body change temperature with time. The principle of Schmidt's method is that if the unit of time Δt is related to the unit of length Δx, by

$$\Delta t = \frac{\Delta x^2}{2h^2}$$

then the temperature of a given point at a given time is the mean of the temperatures which were possessed Δt earlier by two points, Δx on each side of it (in the direction of heat flow).

The method requires no knowledge of the mathematics involved and is applicable to very complex conditions of initial heat distribution or surface temperatures. For problems such as the present, it has the disadvantage of either lacking precision as to temperature gradients near mold surfaces soon after the mold is filled, or requiring many steps in a given time period.

The point is illustrated in Fig. 47. We desire to know the temperature (θ), as a function of distance below the surface, on an infinite chill ($h^2 = 0.173$) 0.7225 sec. after the surface has been instantaneously heated by θ_0. The odd value of time was chosen because it is the Δt corresponding to $\Delta x = 0.5$ cm. At the left of the figure we solve the problem using $\Delta x = 0.5$ cm. and $\Delta t = 0.7225$ sec. The construction of the figure will probably require reference to Sherwood and Reed, but the (approximate) temperature distribution at various simple multiples of 0.7225 sec. is represented by the broken line marked at its lower end by the integers according as the time is 0, 1, 2, 3, etc. times Δt. At zero temperature the approximation is a straight line extending from $X = 0$, $\theta = \theta_0$ at the upper left corner to $x = 0.5$ cm. (Δx), $\theta = 0$ at its lower end. At time 0.7225 sec. (Δt) the line starts at the same point and runs to $\theta = 0$ at $x = 1.0$ cm. ($2\Delta x$). At time 1.445 sec. ($2\Delta t$) the locus starts as before and runs through the points $\theta = 0.50\ \theta_0$ at $x = 1$ cm. ($2\Delta x$) and $\theta = 0$ at $x = 115$ cm. ($3\Delta x$). The interpretation of the remaining lines up to $t = 5\Delta t$ can probably be followed.

The line for $t = 0.7225$ sec. has been transferred as a dotted line to the right half of the figure opening the scale of abscissa in the ratio of 5 to 1. The dots represent the analytically computed values indicating a very poor agreement.

The graphic solution was repeated making $\Delta x = 0.1$ cm., which involves changing Δt to $\frac{0.7225}{25}$ sec., and means that 0.7225 sec. is now 25 Δt instead of Δt. In the new solution the line for 25 Δt represents with greater precision, the same state as Δt in the original. The broken continuous line is the result and now evidently is a close approach to the correct values.

The uncertainties are of a character particularly affecting the slope

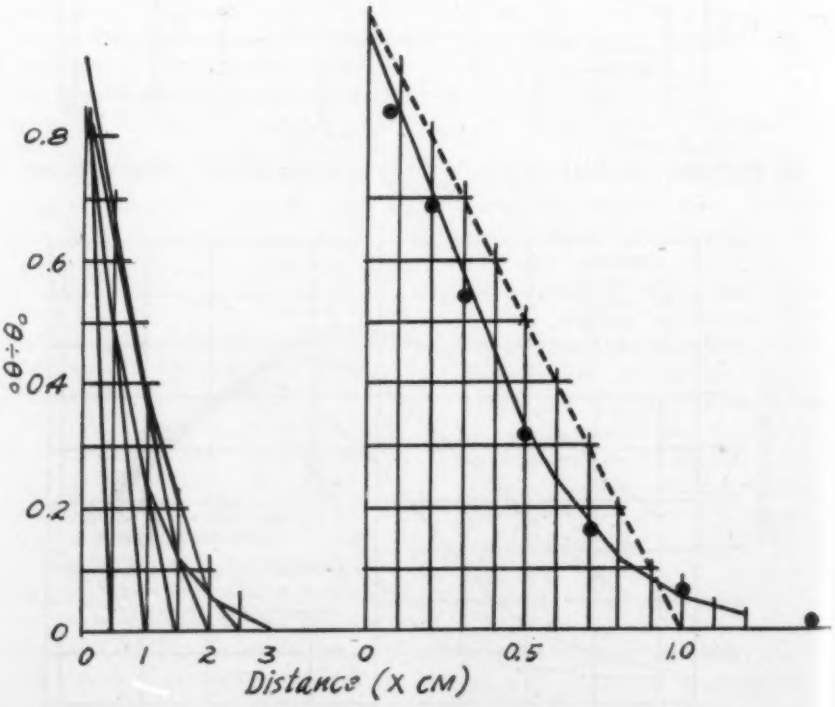


Fig. 47—Successive Approximations to Heat Distribution in an Infinitely Thick Slab by Schmidt's Method.

of the line when $x = 0$, a value we would much like to have precisely in order to compute heat input. Lacking it, we must proceed from a calculation of heat content using the mean temperature. Despite its limitations Schmidt's method permits us to solve, even though laboriously, some problems too complicated for analytical expression. Since the procedure is little known to foundrymen, or even to engineers, a few applications may usefully be indicated.

One might compute the temperature distribution in a chill of known diffusivity and thickness if the time temperature relation on its two faces is known, as for example in Junge's data already plotted. To do this one divides the chill thickness into a convenient number of steps (Δx) and computes the required Δt. One then draws a diagram consisting of two vertical boundaries separated by a distance representing the chill thickness and erects vertical ordinates at intervals of Δx. Along the boundaries one marks off the temperatures existing at the series of simple multiples of Δt on each face, using the known time temperature relations and then constructs θ vs. X curves by the usual methods. Junge's data do not extend to the origin ($t = 0$) so are not suited to our evaluation. Using extrapolated temperatures up to 12 sec., the approximation is grossly inaccurate; from there on to 45 sec. the temperature gradient approaches a straight line. This condition cannot be permanent because the back face heats long after that time.

Effect of Chills

A very important problem which is poorly adapted to analytical treatment is that of the temperature distribution in a chill backed up by molding sand whose outer surface is maintained at constant temperature. For example, a chill 2.75 cm. thick is backed up by sand so thick that the outer surface does not reach room temperature. What are the temperature gradients in the chill and sand as a function of time if the chill surface is suddenly maintained at a temperature θ_0 above room temperature. To solve the problem, it is desirable to choose Δx so that the chill thickness is $(n + \frac{1}{2})\ \Delta x$ where n is some whole number. In our problem $\Delta x = 0.5$ cm. will be convenient for illustration ($n = 5$). Then as before $\Delta t = 0.7225$ sec.

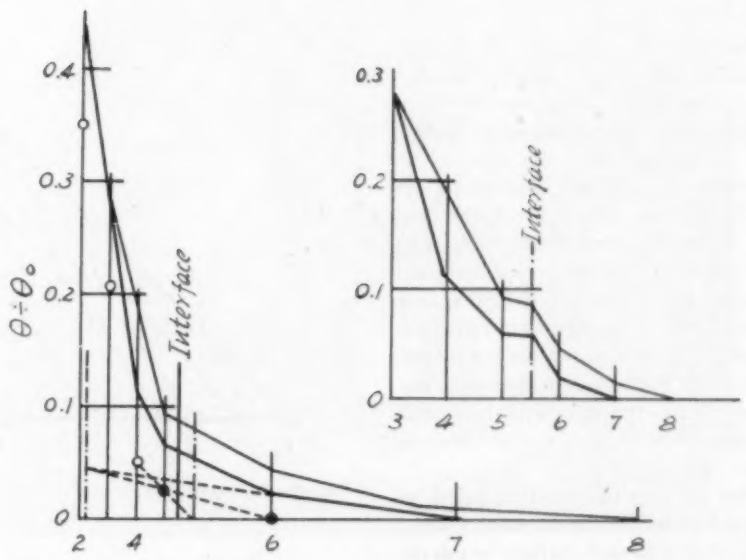


Fig. 48—Temperature Distribution in a Chill Backed by Sand. By Schmidt's Method.

Since the diffusivity of sand is 0.0049, the Δx for sand corresponding to $\Delta t = 0.7225$ sec. is 0.084 cm.

It is quite easy to treat either the iron chill or the sand body by the conventional Schmidt method, but special methods are required to connect the two constructions. In our present problem we can carry the usual construction forward to the point where we locate a point distance $4\Delta x$ below the surface at time $5\Delta t$. We know that this point should be connected with the point $5\Delta x$ for $t = 5\Delta t$, but 5Δ is beyond the sand chill interface.

The temperature gradients on the two sides of the interface must be inversely as the conductivities of the corresponding materials (0.1436 for steel and 0.0037 for sand). If, therefore, we magnify the x scale in this ratio, (practically 6 to 1) for points in the sand body as compared with points in the metal body, a line of constant slope represents the proper change of $\frac{d\theta}{dx}$ when crossing the interface.

In Fig. 48 points are set off along the horizontal axis representing successive steps of Δx. To save space, the steps do not begin at 0, the chill surface. The linear distance corresponding to Δx varies in the ratio of $\frac{0.084 \times 6}{0.5}$ to 1. The actual value of one step in distance is smaller in sand than in steel for a given step in time (here 0.72 + sec.), but is magnified as required by the relative conductivities. By the usual successive steps the open circles at $2\Delta x$, $3\Delta x$, $4\Delta x$, can be obtained without need to consider a change of material. The point at $6\Delta x$ is obviously at 0 as marked by the dot, and that at $5\Delta x$ is obtained by joining the one at $4\Delta x$ to the base of an ordinate located $\frac{1}{2}\Delta x$ (steel scale) to the right of the interface and marking the intersection of this line with $5\Delta x$ as shown by the dot. This construction will be plainer later on.

To obtain the line for the next time interval we proceed as usual so long as we remain exclusively on one side or the other of the interface. To obtain the points distant $\frac{1}{2}\Delta x$ on each side of the interface a special construction is made. Ordinates are erected, as dot and dash line distant by $\frac{1}{2}\Delta x$ each side of the interface but with the scale reversed; i.e., the ordinate located in the chill is at a distance proper for sand and vice versa.

The line representing the temperature gradient is extended as necessary to intersect these two construction lines and these intersections are used instead of the points actually on the locus in determining the intermediate points. Two lines (heavy and light) are plotted in the figure for two time intervals beyond that corresponding to the circles. In the upper right corner of the figure, these two lines are re-plotted with a uniform linear value of Δx to show the actual change of slope $\frac{d\theta}{dx}$ at the interface. Radial heat flow in cylindrical or spherical objects can be solved by the use of logarithmic or reciprocal scales for measuring the

radius.

The preceding method can be extended to take care, approximately, of a change of conductivity with temperature. The process is laborious, involving the selection of a desirable Δt and the subdivision of the solid into which heat diffuses into layers of predetermined thickness, each of which is momentarily assured of constant temperature and conductivity. The mean temperature of each is re-computed for each new time interval and corresponding values of Δx changing with time and distance below the surface calculated.

This process has been applied to the problem of the semi-infinite sand mass with constant surface temperature, assuming that the sand transmits heat by both conduction and radiation. In that case the apparent conductivity is something like:—

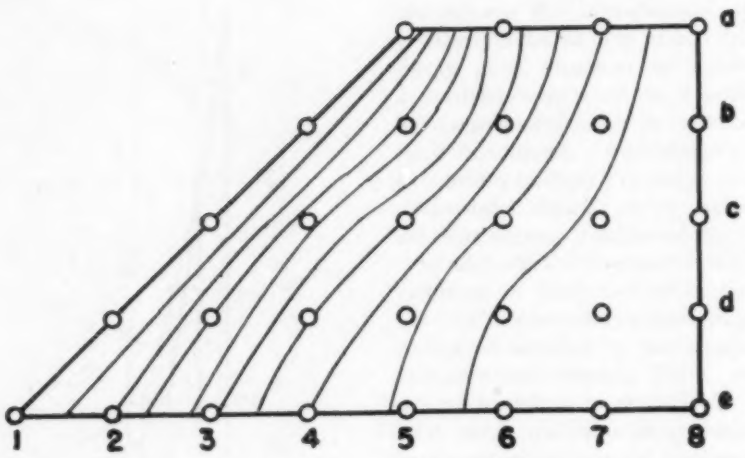


Fig. 49—Isothermals at Intervals of 0.1 θ in a Sand Body, Two Non-Parallel Surfaces Held at Constant Temperature.

$$k = 0.0037 + 16\theta^3 \times 10^{-13}$$

when θ is the absolute temperature (degrees Kelvin) and k is in calories per second per square cm. per degree Kelvin (or Centigrade) per cm. An analytical solution of the problem has been beyond those mathematicians to whom it was presented. A solution by the Schmidt method seems to show that under these conditions after a time interval of about a minute the rate of heat input becomes nearly constant, somewhat similar to the relation of thickness of metal frozen to time observed by Briggs and Gezelius and by Troy.

The Schmidt method has been described at somewhat excessive length because it is little known, requires no higher mathematics, and can solve, laboriously, it is true, very complex problems. Further study in the references is recommended.

A numerical method similar in principle can be applied to two and three dimensional heat flow. For the two dimensional case:—

$$\Delta t = \frac{\Delta x^2}{4h^2}$$

Instead of averaging graphically, we average numerically. As a crude example, consider a trapezoidal mass of sand as shown in Fig. 49, whose sloping surface is suddenly raised by θ_0 as by pouring in metal while the back face is maintained at room temperature as by a water cooled chill. The upper and lower surfaces are insulated. Designating selected stations in the sand by a letter and number corresponding to the ordinates marked in the figure, we can compute temperature at successive times, as recorded in Table 9, for six successive times.

An entirely different approach to heat flow problems arises out of similarities between heat conduction

Table 9

TEMPERATURE ELEVATION AT VARIOUS LOCATIONS AND TIMES IN SOLID SHOWN IN FIG. 49 IN TERMS OF ORIGINAL SURFACE TEMPERATURE ELEVATION

Line	*Time*	*Columns*							
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
a	0					1	0	0	0
	1					1	0.25	0	0
	2					1	0.31	0.06	0
	3					1	0.39	0.09	0
	4					1	0.42	0.13	0
	5					1	0.71	0.16	0
	6					1	0.72	0.25	0
a	0				1	0	0	0	0
	1				1	0.50	0	0	0
a	2				1	0.56	0.19	0	0
	3				1	0.61	0.22	0.06	0
	4				1	0.62	0.29	0.08	0
	5				1	0.67	0.31	0.11	0
	6				1	0.67	0.42	0.13	0
c	0			1	0	0	0	0	0
	1			1	0.50	0	0	0	0
	2			1	0.50	0.27	0	0	0
	3			1	0.63	0.27	0.12	0	0
	4			1	0.60	0.37	0.12	0.05	0
	5			1	0.62	0.37	0.19	0.05	0
	6			1	0.69	0.42	0.20	0.08	0
d	0		1	0	0	0	0	0	0
	1		1	0.50	0	0	0	0	0
	2		1	0.50	0.25	0	0	0	0
	3		1	0.62	0.25	0.13	0	0	0
	4		1	0.65	0.50	0.13	0.06	0	0
	5		1	0.78	0.50	0.25	0.06	0.03	0
	6		1	0.77	0.56	0.26	0.10	0.03	0
e	0	1	0	0	0	0	0	0	0
	1	1	0.50	0	0	0	0	0	0
	2	1	0.62	0.25	0	0	0	0	0
	3	1	0.72	0.34	0.13	0	0	0	0
	4	1	0.76	0.60	0.18	0.06	0	0	0
	5	1	0.84	0.55	0.31	0.12	0.03	0	0
	6	1	0.85	0.62	0.36	0.18	0.05	0.02	0

NOTE: Non-conducting surfaces are allowed for in averaging by including an additional imaginary layer at top and bottom whose temperature is always that of adjacent layer.

and electrical conduction. It is possible to set up an electrical circuit analogous to a heat path, using electrical potential as the equivalent of temperature, quantity of electricity (coulombs) as the analogue of quantity of heat (calories) and capacities and conductivities which are found in both systems. The laboratory equipment, illustrated in Fig. 50, is extremely complicated and precise—hence expensive—but it exists at one university at least. By studying the electrical behavior of a circuit equivalent to the heat problem to be solved, it is possible to investigate conditions too complicated for mathematical conclusion and do it much more quickly and precisely than by studying the heat distribution in the real system.

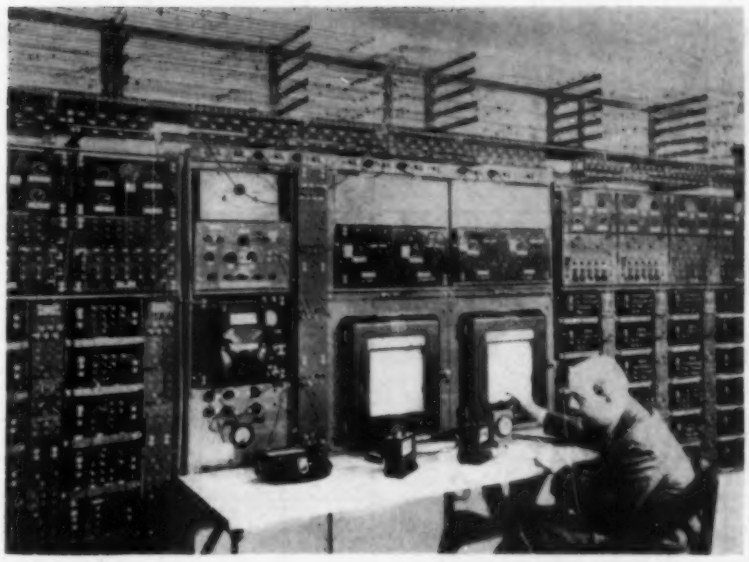


Fig. 50—Apparatus for Studying Heat Flow by Its Electrical Analogue. (Courtesy of Product Engineering.)

Shape of Voids

It is of some interest to know what the shape of the void left when metal freezes may be. Obviously the answer will be different, depending upon the shape of the piece being cast. It is shown by Field that if a cylindrical body cools, losing heat only to its curved surface and not through the ends, then

$$\log y = a \cdot \log x + \log h - 2a \cdot \log r$$

where y is the vertical coordinate on the surface of the shrinkage cavity corresponding to x for a radial coordinate; r is the radius of the casting and h the initial height of liquid poured into it; a is the coefficient of contraction on solidification. It is quite plain from the form of this equation that when $x = 0$, the logarithm of y is negatively infinite, and hence under these conditions the centrol pipe will always extend to the bottom of the casting. If the mold is not cylindrical but has a larger cross-section at the bottom than at the top, then for molds of similar cross-section, without loss of heat at the top or bottom, Field finds that

$$\log y = \log h + \frac{2a \log (x/r_1)}{\sin \theta} - \frac{a(r_2 - r_1)}{2.3X} + \frac{ar_2}{2.3r_1} - \frac{a}{2.3}$$

Here r_1 is the radius at the top and r_2 that at the bottom of the mold, r_2 is thus greater than r_1. If the conditions are reversed and r_1 is greater than r_2, then the resulting equation is the same as above except that a plus sign is substituted for the minus sign before the third term. When the mold is cylindrical, or greater in diameter at the bottom than at the top, the shrinkage cavity extends clear through to the bottom under the conditions assumed, If, however, r_2 is less than r_1, then the surface of the shrinkage cavity cuts the axis of the mold at right angles at a finite value of y.

Since even our simple cylindrical mold cannot be filled instantaneously, the metal in the bottom is presumably colder than the metal in the top, which represents, so far as cooling or freezing rate is concerned, the equivalent of a mold tapered so as to be smaller at the bottom than at the top.

It is altogether possible for simplified conditions corresponding only approximately to the circumstances occurring in practice, to calculate how far within a body the shrinkage void should be found. The calculation was made by the present writer in another connection for a copper sphere poured into, and cooling in contact with a copper chill (actual contact would not be maintained) and neglecting the latent heat of fusion of copper. In Fig. 51, the temperature in such a sphere 20 cm. in diameter, is plotted, each line representing the temperature of a separate isothermal surface, which would be a spherical surface; the several isothermals being located at various distances from the surface as marked. Assuming that

$$\frac{\theta}{\theta_0} = 0.75$$

that is to say, that the metal was poured at a temperature such that the freezing point is three-fourths of the metal's temperature on the conventional Centigrade scale, then the freezing point in the diagram is represented by the lower dot and dash line. Let us consider, for example, the moment in time when the sphere has frozen so far that the radius of the liquid body is 5 cm. This time ordinate is located by finding the intersection of the 5-cm. isothermal curve with the 0.75 line for the value of $\frac{\theta}{\theta_0}$.

Evidently at lesser radii than 5 cm. the metal is liquid; at greater, it is solid. The cooling rate of any given isothermal spherical surface at this moment can be determined by drawing a tangent to its time temperature curve at the point of intersection of the latter, with the time ordinate determined by the intersection of the 5-cm. curve with the freezing point. Knowing the coefficient of thermal expansion of the metal, we could translate these curves into shrinkage rates. We can then, by averaging, determine the shrinkage rate of the solid and liquid metal respectively at the moment when freezing has progressed inward by half the radius. A similar construction can be made for the other thicknesses of solidified layer and curves can be drawn representing the rate of shrinkage of the solid and of the liquid as a function

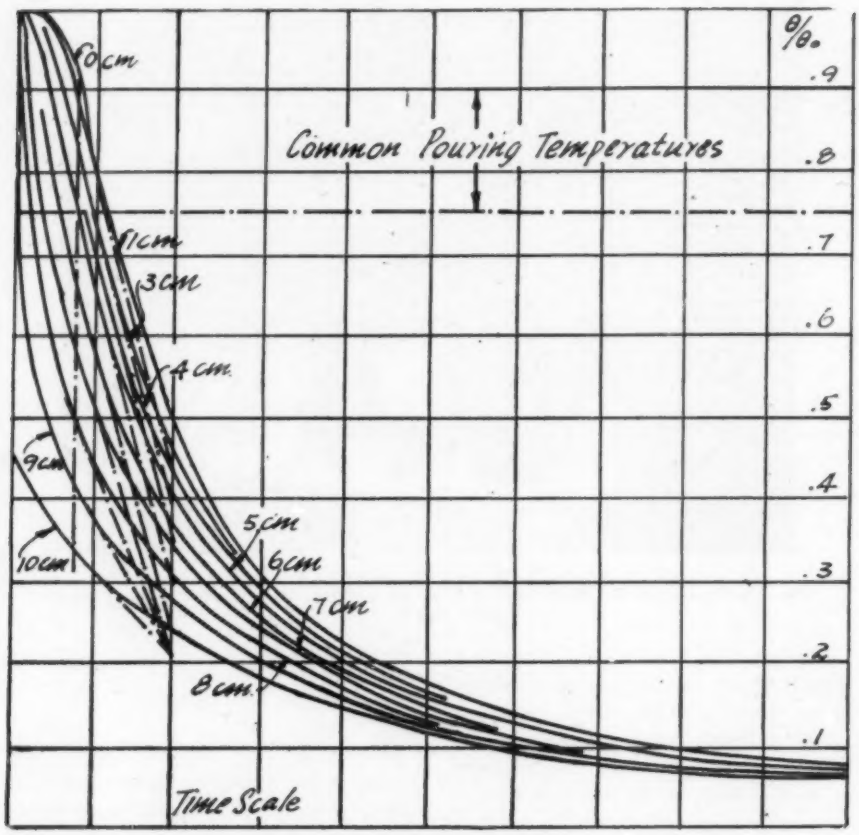


Fig. 51—Rate of Contraction of Metal within a Cooling Sphere.

of the thickness of the frozen layer. These curves will be widely different, depending upon the degree of superheat, as is shown in Fig. 52. Here two pairs of curves are shown, representing a superheat corresponding to

$$\frac{\theta}{\theta_0} = 0.75 \text{ and } \frac{\theta}{\theta_0} = 0.90$$

That is to say, in one case the superheat is one-third the melting point and in the other case one-ninth. With the greater superheat, the solid and liquid curves never intersect, so that the liquid center always contracts faster than the solid exterior. A shrinkage void then begins to form from the very moment of freezing, but appears not as an interior cavity but as a pipe extending inward from the surface. In the second case, with cooler pouring, the liquid contracts more slowly than the solid, which means that the solid has to be stretched by creep, until the radius of the molten metal is between 5 and 6 cm. Thereafter the liquid contracts more rapidly than the exterior, and a shrinkage void begins to form, buried by something over 4 cm. below the surface of the sphere.

The particular conditions for which this calculation was made are of little interest in practice and were chosen merely to illustrate the problem. It is of some interest, however, to note how pouring temperature can affect the location of a shrinkage void in a casting, even in over simplified cases.

Conclusion

If the writer has been at all successful in his purpose, it will now be clear that most of the problems connected with the solidification of metal, both in the abstract sense and in the sense of making solid castings, can be solved by the application of classic principles of physics. The existing difficulties arise out of the experimental handicaps in determining some of the constants involved, and out of the mathematical difficulty incident to evolving solutions corresponding to the rather complex cases occurring in the most ordinary foundry practice. What is really the most fundamental engineering problem in the foundry industry—the making of castings—has been almost neglected.

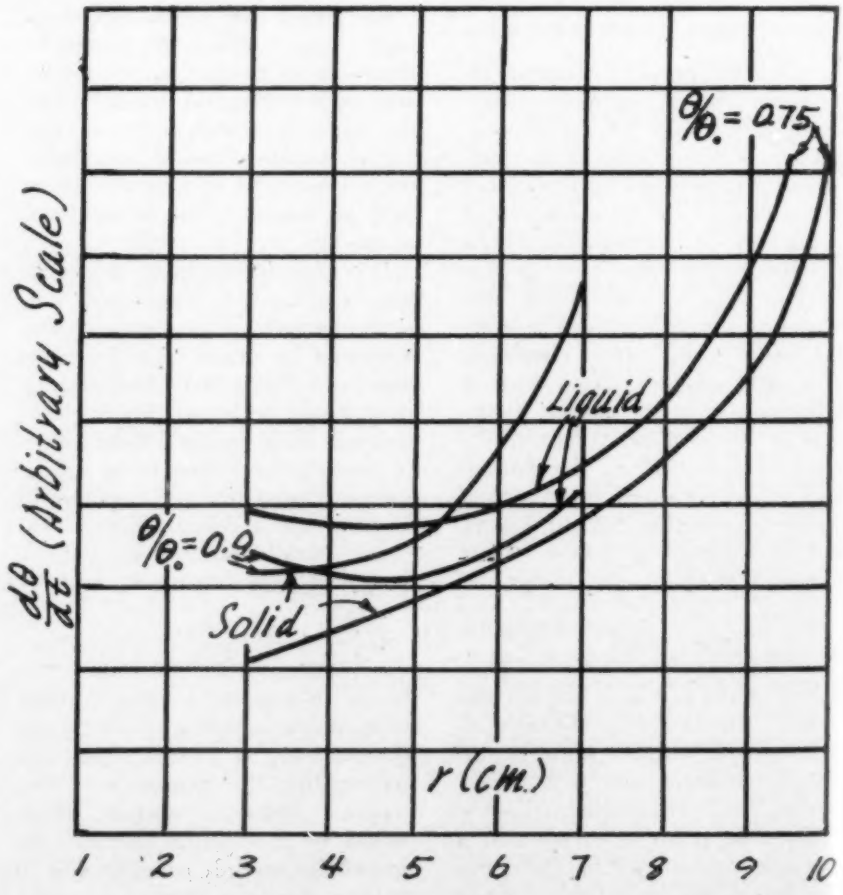


Fig. 52—Relative Shrinkage Rate of Surface and Interior of a Freezing Sphere.

Addressing the last International Foundry Congress in London in 1939, Sir W. Lawrence Bragg, Cavendish Professor of Physics at Cambridge, made the statement that what industry most needs is a group of people who can interpret the findings of the pure scientist for the benefit of industry.

This speaker would like to present his "nickel's worth" in support of Prof. Bragg's position. If some physicist can be persuaded to deal with the mathematics of heat conduction under the circumstances that interest a foundryman, and if our engineers can take these facts and translate them into operative principles, then our foundries will be able to make, systematically and continuously, and without so much "cut and try," some very superior castings.

Bibliography

The following bibliography comprises the more interesting and fruitful sources from which this writer's knowledge of the solidification of metals was obtained. Most of the statements and data in the body of the paper will find confirmation somewhere in these citations. The list is, however, by no means complete. Many useful publications which parallel information in this reading list have been omitted; also some original sources, reference to which will be found in this list. In a few cases illustrations are derived from lantern slides or data sheets in the files of the Research Department of the National Malleable and Steel Castings Company, the origin of which can no longer be traced. In those cases it has been impossible to credit the proper authors or publications.

The writer takes this opportunity of tendering his apologies to those from whom credit may have been withheld under these circumstances.

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A STUDY OF MOLDING METHODS FOR SOUND CASTINGS

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• ***Official A.F.A. Exchange Paper presented at the 42nd Annual Conference of the Institute of British Foundrymen, London, June 15 and 16, 1945. Fundamental principles of metal solidification in the production of sound castings are discussed.***

A LONG accepted definition of engineering is "The art of organizing and directing men and of controlling the forces and materials of nature for the benefit of the human race." During war time the last phrase of this definition is distorted to read "for the *destruction* of the human race." It is hoped that these international exchange papers may contribute toward peaceful, scientific relationships between nations and peoples by fostering a cordial exchange of ideas.

This paper has to do with that part of the definition of engineering given above which deals with "forces and materials of nature." Let us hope we may soon direct them exclusively for the benefit, and not the destruction, of the human race.

The future of any foundry, indeed of the foundry industry, hinges largely on its ability to produce sound castings regularly. Freedom from casting defects is really as important to the user as the particular composition of metal desired. Indeed, sound castings not only satisfy the customer, but they also insure profit for the foundry and assure repeat business.

Satisfactory castings are dependable in service, cost the least to machine and to fabricate into machines, and, therefore, can command the highest prices for the foundry.

To produce sound castings, therefore, the greatest attention should be given to the molding details. It is economical and shrewd business to spend time and money to study those molding methods which make good castings.

The factors involved in molding satisfactory castings are the same for all metals. Let us see how simple these factors are and how easily and sensibly they can be applied.

I. Clean Metal and Gate Design

Clean metal poured into the mold cavity is of first importance. To this end the use of skim gates, slag traps, swirl gates, etc., are effective. In low melting point metals, such as aluminum, the use of coarse steel wool or a perforated steel sheet as a skimmer over the sprue are effective.

In aluminum and magnesium pouring, agitation causes the trapping of some of the surface scum. This is prevented by using slotted sprues. See Fig. 1. The thin deep slots and the angle of the pouring gates permit the metal to enter the mold with minimum agitation.

The cross section of gates should be rectangular rather than square or round where they are attached to the casting, except when they are part of the feeding system. The rectangular rather thin gate section promotes more rapid freezing, therefore, produces soundness at the gate. The total area of the gates should be sufficient to have the maximum pouring speed without washing the sand. Filling the mold with adequately hot metal, which also means rapid pouring, promotes soundness by giving time for removal of slag and gas inclusions.

II. Position of Gates and Feeders

Controlled progressive solidification is not peculiar to steel foundry practice alone, where Briggs, Gezelius and others did the early work, but it is applicable wherever molten metal is freezing. The earliest application of this principle was in making sound steel ingots. By comparing the ingots of Fig. 2, it is seen how sound ingots have been controlled in the steel mill by the use of "hot tops" to provide molten metal for feeding.

The principle involved in controlled progressive solidification is based upon the fact that the coldest metal and the thinnest sections freeze first and the direction of freezing shall move, without interruption, toward the heaviest sections and/or the hottest metal in the mold. There

[1]Research Met., International Nickel Company.

Fig. 1. Motor Housing, Magnesium Casting, Top View. Excessive venting by the use of open sand and vent risers is necessary for light metals. Note perforated steel sheet under pouring basin and slotted sprues set at an angle to prevent agitation.

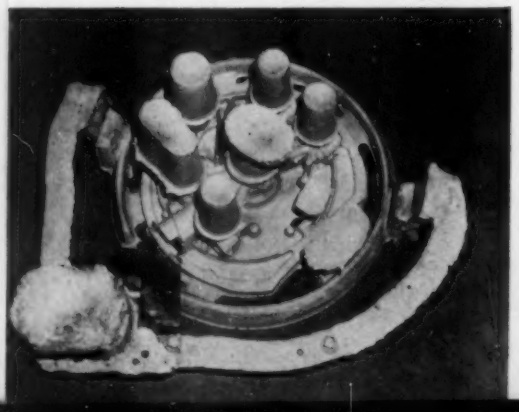
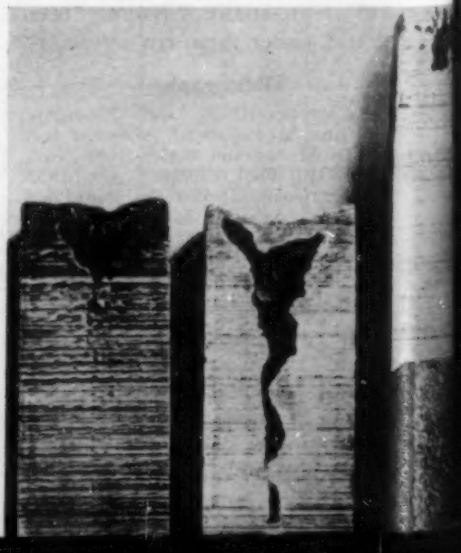


Fig. 2. Sound Steel Ingot production follows principle of controlled directional solidification. Right ingot was kept molten at top with "hot top."



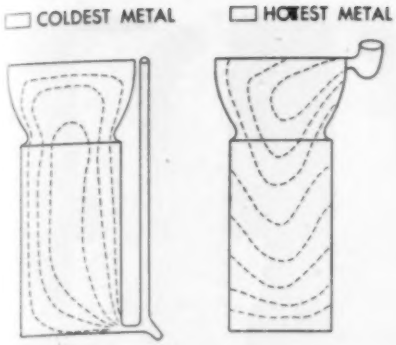


Fig. 3. Effect of top and bottom gating on temperature differential. Position of ingate controls the position of the cold and hot metal in the mold cavity.

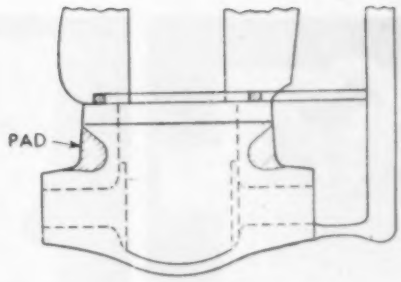


Fig. 4. Padding for controlled directional solidification. Use of pad to provide progressive freezing from the thin to the heaviest section.

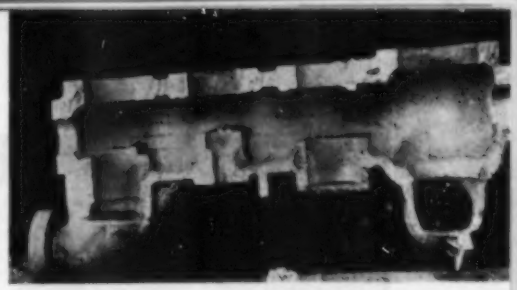


Fig. 5. Destroyer throttle valve steel casting approaching the ultimate in poor design. Note the many light and heavy sections and the accompanying defects.

should be no intermediate light sections or cold metal in a casting which would freeze early and interrupt progressive feeding. The accompanying Figs. 3-12 show how this principle is used to secure sound castings.

III. Effective Feeder Design

Helping risers or heads to feed castings involves several simple details. Proper feeder design and hot metal in the feeder are really applications of the principle of controlled progressive solidification. Under no circumstances should rod feeding or pumping ever be permitted. More castings are lost by rod feeding than are ever saved.

(1) We should have the design such that the feeder is heavier than the section to be fed to be sure that the feeder and its connection will freeze after the casting. Feeders should have 50 per cent greater cross section or, simply, the thickness of the feeder should be 50 per cent greater than the thickness of the casting to be fed. Round feeders are more efficient than square cross sections because of less area to dissipate heat. Feeders attached to the side, particularly in gray iron, promote greater soundness than top feeders.

Fig. 7. Bronze casting gated through the feeder. The coldest metal is at end farthest from feeder. Freezing progresses to the hottest metal at the freezer end. The long runner was used to accommodate the flask equipment, but the length may be shortened. Horn enters riser at bottom. This method of pouring produces cleaner castings than when poured on end. Type of gating shown is practical and effective. Tilting the mold 10°-15° is recommended.

(2) The metal in the feeding head must be at least as hot or hotter than the metal in the castings. See Figs. 4, 7, 8b, 9, 10. To have feeders contain the hottest metal in the mold, the metal should be poured by gating through the feeder. When this cannot be done, hot topping the feeder with an auxiliary ladle of metal will accomplish the same purpose.

(3) Feeders should be kept open to allow the atmospheric pressure to assist gravity in pushing the metal into the casting. See Fig. 16. This is atmospheric pressure feeding. It is accomplished by covering feeders with insulating compounds to prevent a skin of metal freezing over the top and thus permit the atmosphere to push the liquid metal down the feeder.

Blind feeders and shrink bobs are of questionable value unless kept open to the atmosphere with rod cores which should extend from the sand of the mold through to the center of the blind feeder. This device was patented by John Williams* in 1940 and is illustrated in Fig. 11. The success of the Williams feeder depends upon freezing a skin of metal around the casting, which puts it under a vacuum. The atmospheric air pressure in the feeder permeating through the rod core readily pushes the metal into the casting under vacuum.

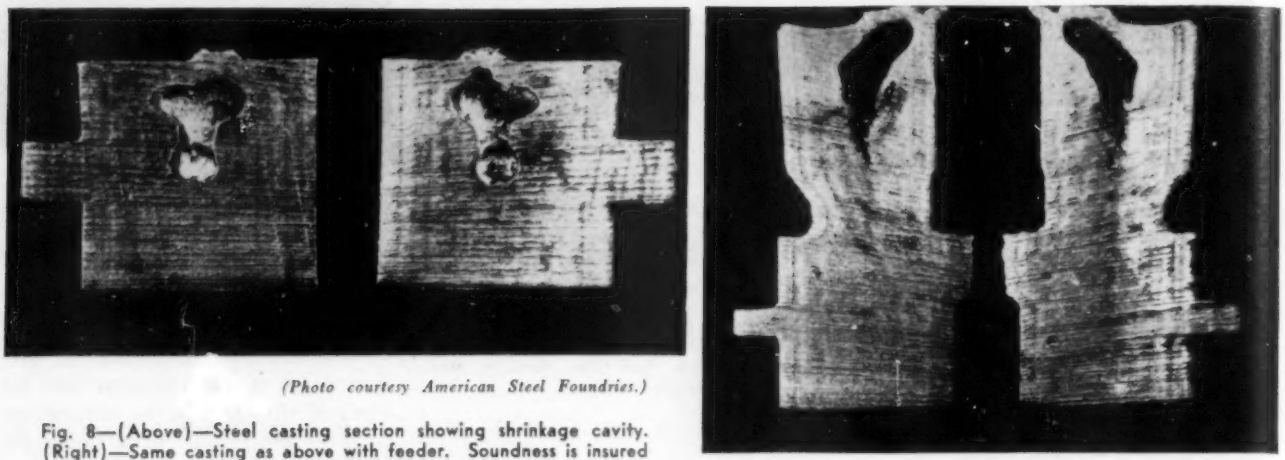
Because of the varying pressure tightness of thin skins of different metals just below the freezing temperature, the Williams feeder provides varying degrees of effectiveness. For example, gray iron is more permeable when hot than steel; therefore, the vacuum created in gray iron castings is less than in steel and the effectiveness of the Williams feeder is decreased.

(4) Feeders should be high enough to afford plenty of hydrostatic pressure. See Figs. 12, 13, 14.

*U. S. Pat. No. 2, 2,205,327.

Fig. 6A. Unsoundness in bronze castings caused by improper gating and risering. Metal bracketed by angle is a blind riser. Shrinkage occurred under risers. The gates enter a thin section opposite a heavier section indicated by arrows. Note the bosses are placed opposite the gates. Porosity occurred at the base of hub.

Fig. 6B. Same castings as Fig. 6A properly gated. Note that the castings were turned so as to gate through the heavy boss, eliminating the need of risers, with excellent results. The photograph shows the castings upside down with the sprue at the right cut off.



(Photo courtesy American Steel Foundries.)

Fig. 8—(Above)—Steel casting section showing shrinkage cavity. (Right)—Same casting as above with feeder. Soundness is insured by use of adequate feeder.

High feeders provide greater hydrostatic pressure in the mold which assists in securing soundness by pushing gas, slag, etc., up through the liquid metal and out of the casting. This same liquid pressure of the molten metal seems to assist in feeding the casting. Sufficient liquid pressure should prevail to be greater than the gas pressure developed at the metal-mold interface.

IV. Feeder Capacity

When the metal in a mold cavity freezes according to the principle of controlled progressive solidification, the coldest and thinnest metal farthest from the gates freezes progressively toward the hottest metal and heaviest section. This means, that the freezing portion of the casting is being fed progressively by the slightly hotter metal ahead. The metal in the feeder then must supply the metal necessary to fill the shrinkage requirements of the entire casting. So often we use feeders adequate for a heavy section of the casting, disregarding the overall shrinkage which may draw from the heavy section before it freezes and which must also be fed by metal withdrawn from the feeders.

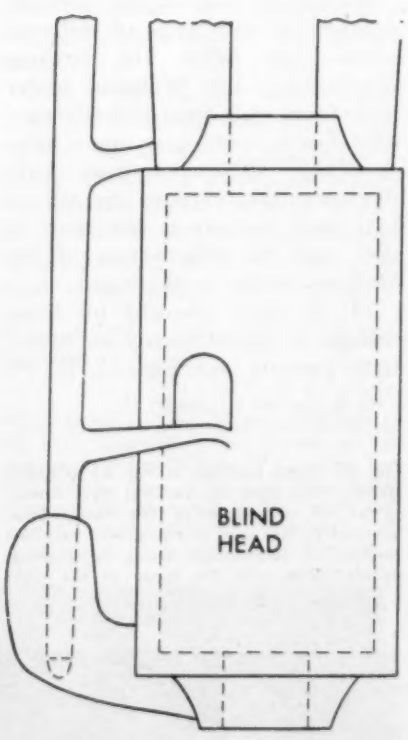


Fig. 9. Step gating and pouring through feeders. These gates permit the first metal to remain at the bottom, the next at the center and final in the top of casting. Feeders receive the last metal poured.

With a great deal of coring, or with "hard" cores, the expansion of cores, and to some extent the molds, will compensate for some of the shrinkage tendencies and indeed, in some cases, may extrude liquid metal through the risers or feeders.

From data in the A.F.A. Cast Metals Handbook on volume changes of irons and steels, the theoretical feeder capacities for ferrous metals has been calculated and is given in Table 1. From the estimated weight of the casting, and employing the above feeder design features, the total weight or volume of the feeders can be calculated. The actual size of the feeder, adjusted for the expansion of cores, etc., will often be smaller than the theoretical size of feeder from Table 1.

V. Feeder Connections

Feeder connections to the casting should have a reduced cross section and be as short as possible. Fig. 16 shows a thin wall of core sand between the feeder, or riser, and casting, which sand becomes incandescent and which permits the feeder connection to remain fluid. This plate core may vary from ⅜-in. to 1½-in., depending on section thicknesses. This method of feeder, or riser, attachment promotes greater soundness under the feeder and permits of easy removal. Generally, a sledge hammer blow will remove the riser or feeder head, since the connection is essentially a deep notch. Fig. 15 illustrates an extreme example of a knock-off feeder. Feeder connection dimensions of one-third to one-half of the casting section dimensions have been found satisfactory by the author. For example, a 1½-in. to 2-in. diameter connection is the maximum that need be used for a 6-in. thick head to feed a 4-in. section.

In Fig. 16, the relationship of feeders to the casting dimensions is given. Note that the side feeder extends below the connection by the same dimension as the feeder thickness. The purpose of depth of side feeders below the connection is to have adequate volume of metal to prevent freezing in front of the feeder connections. Of course, the

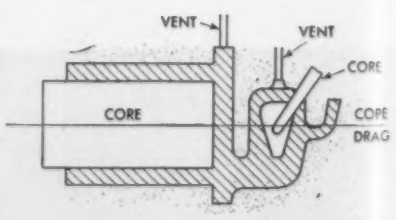


Fig. 11. Atmospheric pressure feeding, illustrating the principle of the Williams atmospheric pressure feeder.

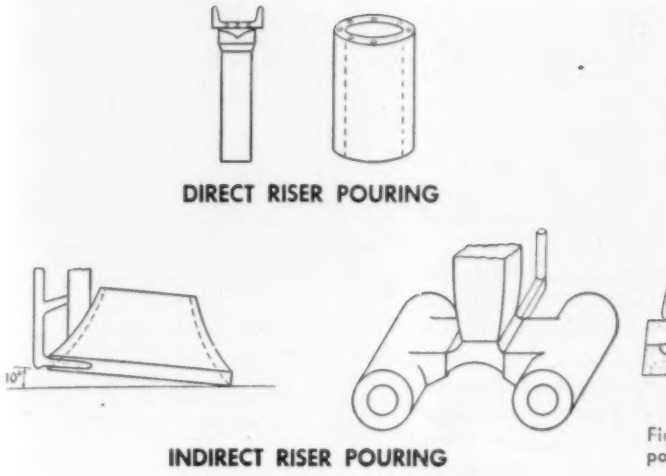


Fig. 10. Examples of gating to provide the hottest metal in the best position for feeding.

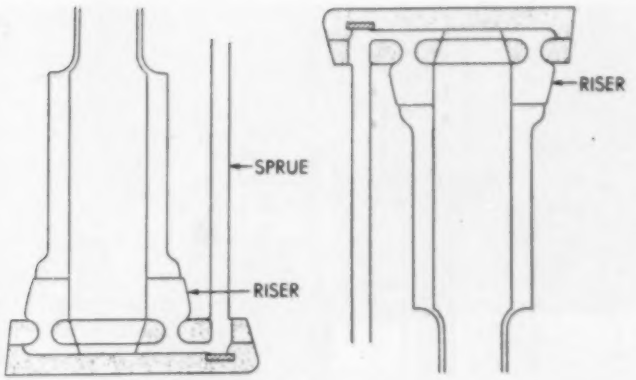


Fig. 12. Complete reversal of the casting for feeding. Poured in position at left. The mold is reversed after freezing the sprue so that the hot riser can feed the casting by gravity.

height of the feeder must be enough to prevent its shrinkage from extending below the feeder connection.

VI. Chills

Chills or denseners are used where feeders cannot be conveniently placed or to control the freezing rate. See Fig. 17. Their purpose is to do the same job as feeders by freezing the metal about as rapidly as it is poured and, therefore, heads for feeding are unnecessary. Indeed, when chills are used, great care must be exercised that feeders are so placed they are not close to chills and do not counteract the chill effect. Chills do cause the shrinks to "move somewhere else," *unless they are placed with due regard to controlled progressive solidification.*

There are certain points regarding chills that must be kept in mind:

A. Chills must be clean. Slightly oxidized or rusty chills cause blows to develop in the casting next to the chill. *Before each use,* therefore, they should be sand blasted and preferably wiped with waste dampened with kerosene to prevent slight rusting in the mold.

B. They must not burn into the casting. Pouring over a chill or excessive agitation of the metal against the chill tends to cause burning in. The aim should be to have the mold poured before the chills have had time to warm up. Chills are protected from burning in by using chill coatings. The writer has found that silica flour mixed with linseed oil to a thin paint consistency is an effective chill coating. This requires heating to dry the surface. Other commercial refractory chill coatings also are available for this purpose.

C. Chills must be large enough to penetrate their densifying effect across the section to be chilled, but not so large and sprawling that they prematurely freeze the metal in the lighter or adjacent sections. Precautions must be taken to prevent chilling the metal beyond the section to be densened or else the metal can not feed into the portion of the casting to be densened.

D. Chills are most effective when the metal moves up to them and is not agitated further. Where possible, they should be furthest removed from the gates so that when the metal pours against the chill, freezing commences.

E. Rapid pouring permits the chill to do its most effective work because the mold is filled with minimum warming up of the chill. The effectiveness of the chill is reduced

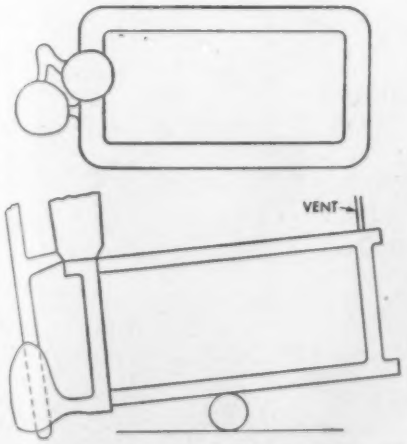


Fig. 13. Partial reversal of casting. Pouring position is shown. Mold is tilted after pouring to provide hydrostatic pressure from feeder.

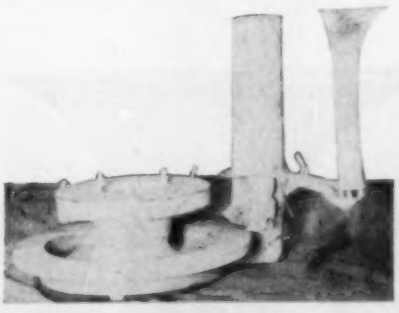


Fig. 14. Bronze casting shows the use of hydrostatic pressure for feeding. This suction cover made of Government Bronze was subject to leakage and chills, risers failing to overcome the difficulty. Risering and gating shown proved successful. Riser is 3 in. in diameter and 10 in. above casting. No riser over casting. Note strainer core and large fillet where metal enters riser. The coldest metal is farthest from feeder and freezing progresses toward the riser, thus assuring soundness. Note high feeder for liquid pressure.

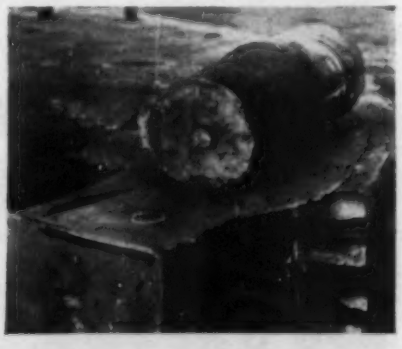


Fig. 15. Extreme application of knock-off feeders. Feeder is 12 in. in diameter "hot topped" for a 16-in. by 14-in. by 22-in. section. Feeder connection is 2 in. in diameter. Density under the riser and easy removal are achieved. (Courtesy, Buffalo Fdy. & Mach. Co.

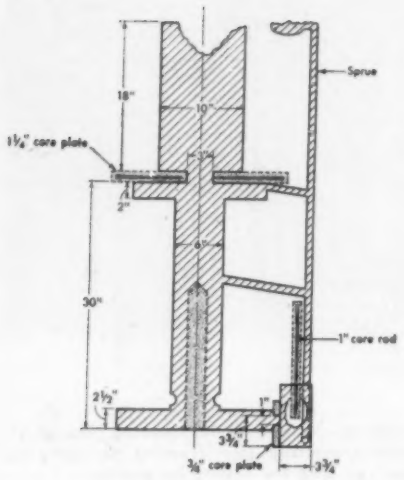


Fig. 16. Mold showing relative dimensions of risers and riser connections and atmospheric risers. Casting involved step gates, Williams risers, gating through the riser and knock-off risers. Reader should trace the freezing from the thinnest sections and coldest metal to heaviest section and hottest metal in the risers.

if it has had time to warm up considerably before pouring is complete or before the metal in contact with the chill is quiet.

F. Chills should be on the side or bottom of the mold cavity for most effective chilling.

VII. Venting Mold Cavities

The importance of venting mold cavities is realized by observing the torch effect often blowing out of a riser or vent during pouring. Indeed, whistlers is a term applied to such vents. When pouring light metals like aluminum and magnesium, special venting is necessary to prevent mold back pressure and thus to help fill the mold. All dead end spots of a mold cavity should be vented so that the metal runs without restraint to every portion of the mold. We should also remember that if gas pressure is developed in a mold, there is increased tendency to force gases into the metal and cause defects. See Figs. 19, 23.

Vents are best designed to be rectangular at the casting to prevent openness and pinholes at the junction with the casting.

In addition to releasing gases of the mold cavity, vents are useful in draining off the cold, and often dirty, metal frequently coming to dead end spots of the mold. By building a pocket in the sand at the top of the vent, a small amount of metal can be drained off. This is illustrated in Fig. 23.

VIII. Porosity Caused by Hot Spots

Pressure castings often show dull, gray to black porous areas in the vicinity of gates, metal knobs or heavy bosses. This dull fracture results from the excessive heat developed by heavy gates, bosses, etc., causing rapid gas generation by the core or mold sand. This defect is distinguished from shrinkage by its dull, dark fracture, in contrast to the bright metallic fracture of pure shrinkage defects. Four approaches to this gas porosity difficulty can prevent these "leakers":

1. If possible, use knife or fin gates. See Fig. 21. Adequate gate capacity can be obtained by using a runner with a long thin gate or many short thin ones. Such a gating system prevents hot spots in the sand or mold. The runner should have greater capacity than the total of the gates to the mold cavity, so that the runner remains full to accumulate the slag, etc., at the top with the gates taking clean metal from the bottom. See Fig. 21.

2. Venting cores and molds freely in the vicinity of the "hot spots." Careful analysis of the mold around the porous area often reveals inadequate venting of the cores or of the external mold sand to release the high gas pressure developed at the metal-sand interface.

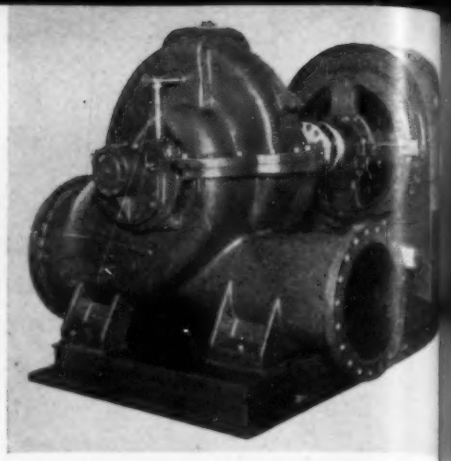


Fig. 17. Pump casing showing metal joints that would most likely require chilling for pressure tightness.

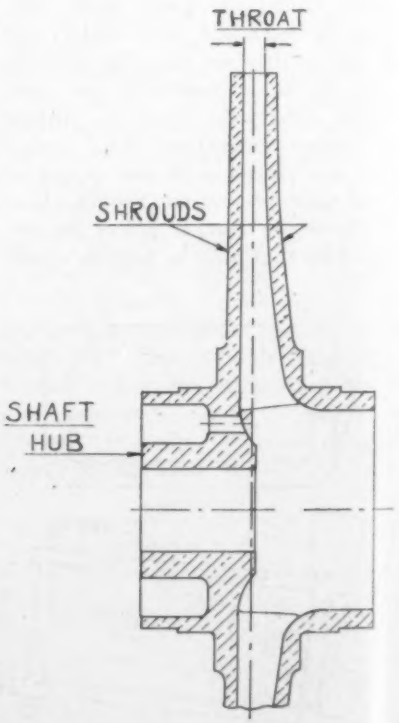


Fig. 19. Section of large impeller shown in Fig. 18. Metal poured with the axis horizontal through feeder attached to the hub, poured rapidly and freely vented with rectangular vents at the top of both shrouds. (Courtesy, Le Courtenay Co.)

Fig. 18. Pump impellers of large diameter and narrow volutes require special foundry technique. (Courtesy, Le Courtenay Co.)

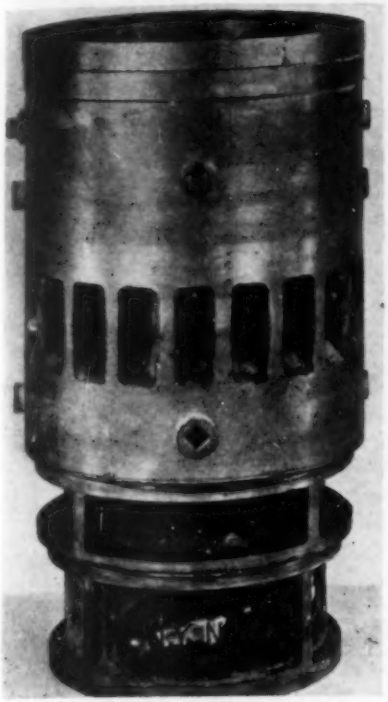


Fig. 20. Jacketted Diesel Engine Liner Machined.

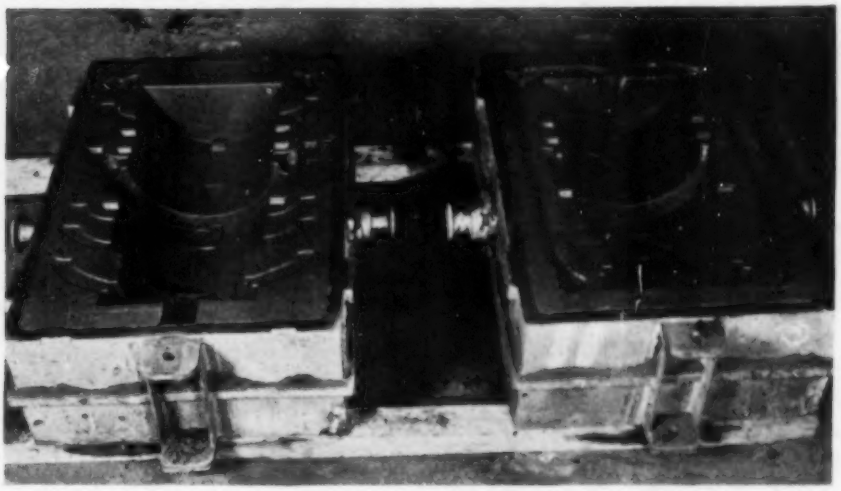


Fig. 21. Drag and cope of green sand mold for Liner shown in Fig. 20. Pouring sprue at back. Note dirt trap (dam) near sprue; knife gates in drag and a slag trap (riser) at this end of runner.

3. We should bear in mind that the mold and core gas pressures can become very high when molten metal touches the sand surfaces. High sand permeability and venting freely can assist in preventing these pressures from building up. However, to provide a safety factor against these gas pressures, it is recommended that the liquid pressure of the molten metal should be so high that it exceeds the maximum gas pressure at the sand face. High liquid pressure is achieved simply by high risers, mold vents and pouring basins. Figs. 14 and 23 show the height of the molten metal used for these pressure castings. Note the risers along the side of the casting in Fig. 23, which were placed there primarily to provide high liquid pressure along the cylinder for some little time after pouring. The excessive cores used for this casting expanded after pouring, which more than compensated for the shrinkage of the metal. Feeding from risers, therefore, was unnecessary.

4. The writer has also found rapid pouring of pressure castings at the proper temperature (usually quite hot) is essential. This permits easy removal of gases, dirt, etc., through the molten metal. Cold metal or slow pouring develops many areas of cold sluggish metal which do not freely permit the removal of gases, dirt, etc.

Summary

A thorough understanding and application of only a few principles are necessary to make sound castings, no matter what metal is poured.

(1) Pouring gates should be designed so that clean metal enters the mold quietly and fills the mold rapidly. Rectangular cross sections are generally preferred over square or round gates.

(2) Controlled progressive solidification assists the freezing of the

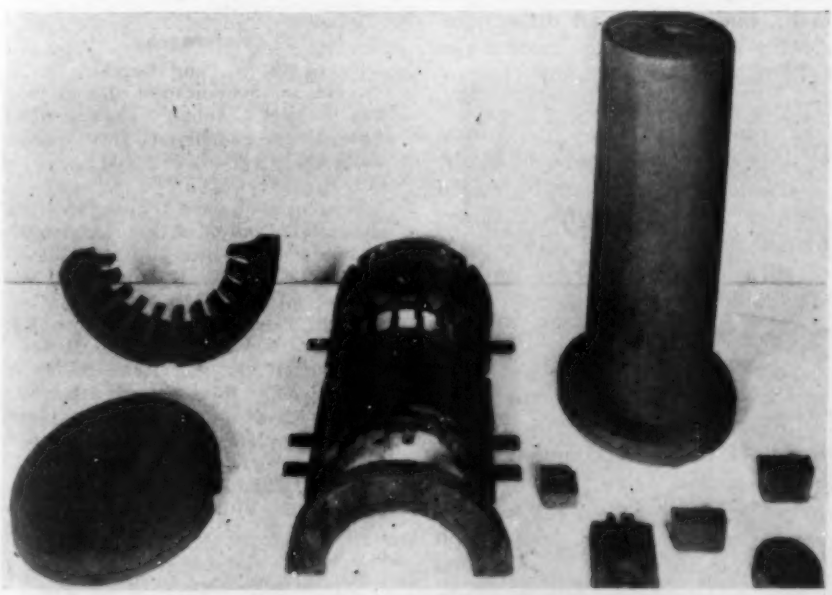


Fig. 22. Oil sand cores for Liner shown in Fig. 20.

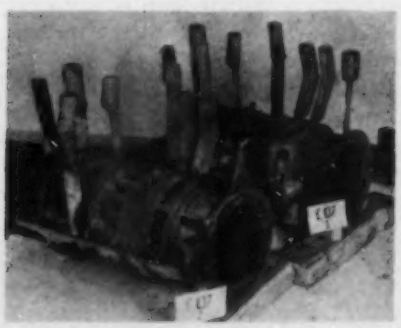


Fig. 23. Liner shown in Fig. 20. As cast, showing "flow off" vents, side and flange feeders provide liquid pressure.

Table 1

THEORETICAL FEEDER CAPACITY[1]

	Soft Gray Iron 3.50-400 per cent TC	*Medium Carbon Gray Iron 3.00-3.25 per cent TC*	*High Test Gray Iron 2.50-2.75 per cent TC*	*Ni-Resist*	*White Iron Chill Cast*	*White Iron (Malleable)*	*Steel*
POURING TEMPERATURE	2450° F. (1350° C.)	2650° F. (1450° C.)	2650° F. (1450° C.)	2650° F. (1450° C.)	2500° F. (1370° C.)	2750° F. (1510° C.)	2950° F. (1620° C.)
WEIGHT OF FEEDER (lbs.) (per 100 lbs. of casting)							
ROUND[2]	1.75	11.0	13.0	15.0	15.2	19.75	19.75
SQUARE[3]	2.80	17.6	20.8	24.0	24.4	31.60	31.60
VOLUME OF FEEDER (cu. in.)[4] (per 100 lbs. of casting)							
ROUND[2]	7.00	44.0	52.0	60.0	60.8	79.00	79.00
SQUARE[3]	11.20	70.4	83.0	92.0	96.7	126.50	126.50
Liquid contraction[5] (per cent)	2.2	2.4	2.2	2.1	0.25	1.75	2.72
down to freezing temperature	2100° F. (1150° C.)	2250° F. (1230° C.)	2280° F. (1250° C.)	2300° F. (1260° C.)	2460° F. (1350° C.)	2460° F. (1350° C.)	2650° F. (1450° C.)
Shrinkage during freezing (per cent)	—1.6 (expansion)	1.8	2.8	3.5	5.50	5.50	4.50 (Ave.)
Total shrinkage pouring temperature to solid at freezing temperature (per cent)	0.6	4.2	5.0	5.6	5.75	7.25	7.22
Weight of metal to be fed into 100 lbs. of casting (lbs.)	0.7	4.4	5.2	6.0	6.10	7.90	7.90

[1] Refer to section IV on Feeder Capacity.
[2] 40 per cent feeding efficiency maximum for round feeders.
[3] 25 per cent feeding efficiency with square feeders and cold metal.
[4] All ferrous metals weigh .25 lb. per cu. in.
[5] Liquid contraction per 100° C., for irons 1.1 per cent, for steels 1.6 per cent.

casting to begin at the coldest metal and/or the thinnest section and to move progressively toward the hottest metal and/or the heaviest sections.

(3) Design and pour feeders so they will assuredly feed castings by conforming to the principles of controlled progressive solidification. Allow plenty of pressure to act on the molten metal in a feeder. Be sure the capacity of feeders is sufficient for the castings.

(4) Knock-off feeders are convenient to remove and do feed adequately with soundness under the feeding head or riser.

(5) Chills or denseners are used where feeders are impracticable or where we wish to assist the freezing rate.

(6) Adequate venting the mold cavity permits filling the mold easily by preventing back pressure. Gas absorption by the metal in the mold is also reduced by good venting. Mold cavity vents or whistlers are convenient to drain off cold metal, dirt, etc.

(7) Porosity with a dull gray to black fracture is a result of core or mold gas. This can be prevented by careful venting of cores and molds, avoiding hot spots, and by using high liquid pressure.

Conclusion

In a jobbing shop, where a wide variety of castings are made, complete records of the successful molding practice of each casting should be kept. The best record is a photograph of the casting as poured indicating all gates, feeders and chills, and marking all dimensions. At any future date, the casting can be made without trouble by referring to the record.

The foundry industry's greatest challenge has been, and still is, the production of consistently sound castings. In meeting this challenge, foundrymen should be ever vigilant of their foundry processes and always holding them under the light of scientific reasoning.

Acknowledgment

The writer wishes to express his appreciation especially to C. W. Briggs of the Steel Founders' Society, Cleveland, Ohio; H. F. Taylor of the U. S. Naval Research Laboratory, Washington, D. C.; and Joseph Nixon of the Whitehead Metal Products Company, Buffalo, New York, for the detailed instruction received on the principles for making sound castings. Further appreciation is expressed for the many suggestions received from the writer's associates of The International Nickel Co. and from the many foundrymen with whom the writer has had the opportunity to work in proving that sound castings are made by following fundamental scientific principles.

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CAST IRON FOUNDRY PRACTICE

United States Wartime Developments

By James S. Vanick, Metallurgist,

International Nickel Co.,

New York

• ***Official A.F.A. Exchange Paper presented before the French Foundry Technical Association at the first postwar French Foundry Congress in Paris, Oct. 19-20, 1945.*** ***The United States foundry industry adjusted to the almost exclusive production of war castings and developed practices to meet the greatly increased demands.***

THE author has chosen to write this review in a conversational tone as though exchanging experiences with French friends in the industry. With the advent of the war, communications stopped, and at about that time this review begins. An industry unprepared for war hastened to convert its men, materials and machines into the products for war.

Some gray iron foundries converted completely to the production of aluminum and lightweight alloy castings. The aircraft production program called for multiplying the output of lightweight alloys by approximately 10, and a corresponding increase in lightweight alloy casting production followed.

Production Shift

The foundry industry was also warned that steel would be needed in unprecedented quantities. Steel casting production trebled in quantity. Gray iron production, which had steadily increased up to the opening of the war, increased moderately but shifted in character. With these changes in the industry there was a corresponding migration of skills from one class of work to the next.

In the gray iron industry, production shifted to the manufacture of engine castings, naval and army equipment and munitions. In the course of this change, commercial castings such as automotive, stove and furnace, enamelware, pipe and water works castings became casualties almost as completely as if the country had been invaded and its production stopped.

The facilities for production were converted to the manufacture of bombs, shells, grenades, etc., while pipe shops, which were expert at centrifugal casting, applied their skill to the manufacture of guns, hollow shafts, aircraft cylinders and similar necessary equipment. Some of the most interesting accounts of technical achievements in these fields will emerge in time in the technical press.

As in any similar emergency, a shortage of men, materials and machines accompanied the conversion and production problem. The War Production Board was organized and staffed with able men taken from industry. These men were equipped from their own experience with statistics upon the capacity of industry and they set out to allocate materials and machines in amounts proportional to available manpower.

In an effort to "hold the line" on the cost of commodities, the Office of Price Administration was created, and foundrymen were faced with an acute need to place their cost accounting methods under the cold appraisal of Government officials who were not interested in profits. From this experience, much good will follow. Many foundrymen learned about the treachery of hidden costs concealed in their earlier and less exacting methods of doing business. Each producer filed a standard method for computing costs, which he was compelled to maintain.

This element of conversion brought with it considerable difficulty, particularly as shops moved from an operating schedule of 40 to 48 hours per week to 70 hours per week and operated two shifts or the necessary multiples to keep in production day and night. These changes brought with them overtime pay and wage incentives which added to the prob-

Fig. 1—Carousel system—(A) mold placed on table, (B) facing applied, (C) mold rammed, (D) sand struck off, (E) pattern drawn and mold transferred. Sand for the operation comes from overhead bin. Surplus sand falls through floor grating.

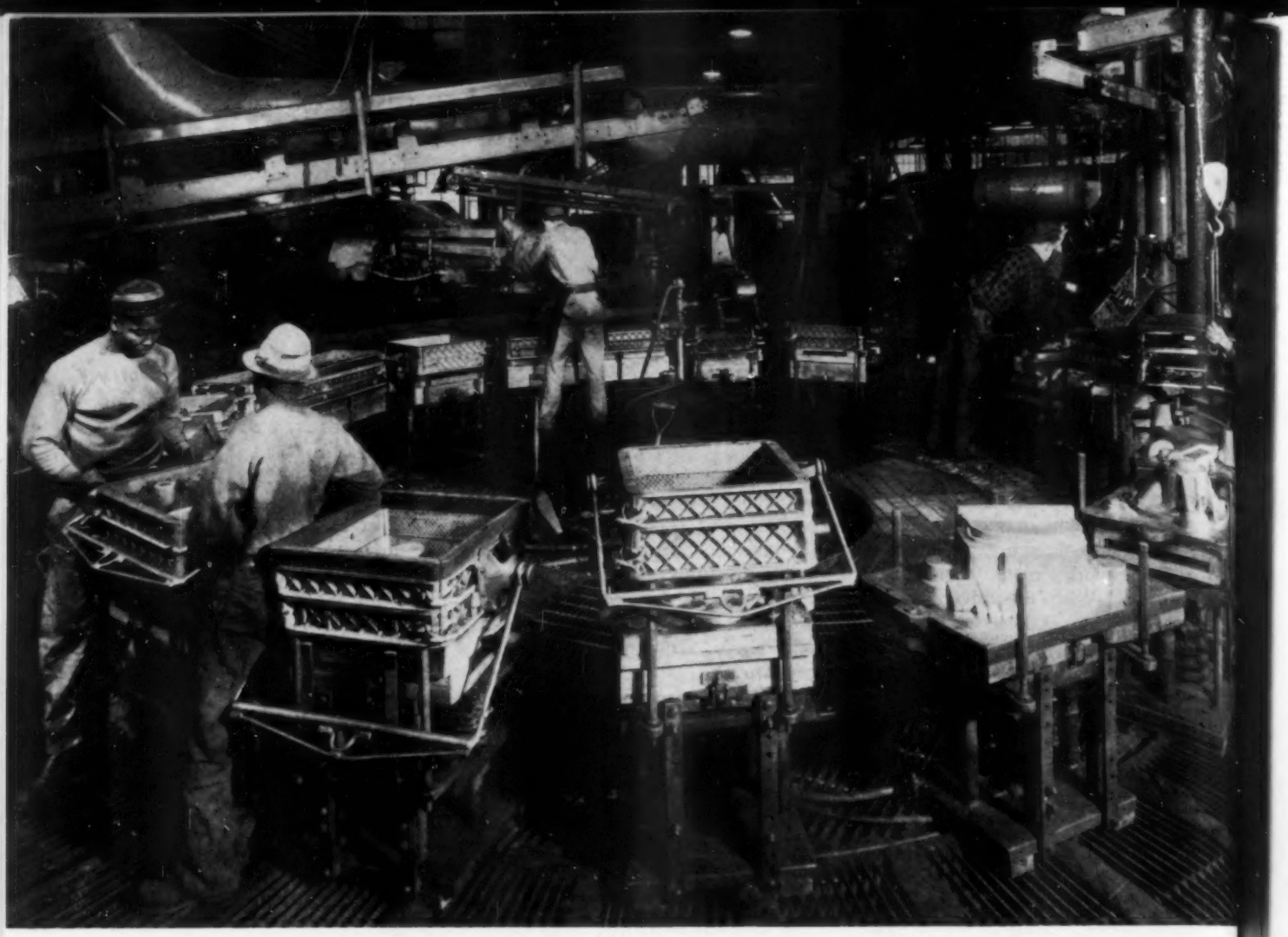


Fig. 2—Eight copes and eight drags molded during each revolution of turntable.

lem of cost accounting and made survival more impressive. Some foundries completely converted their practices and production in the course of this interval, while others gave up in the same time through inability to obtain men or materials or to operate at a profit.

Government authorities took charge of raw materials and, through the allocation system, controlled the production of castings.

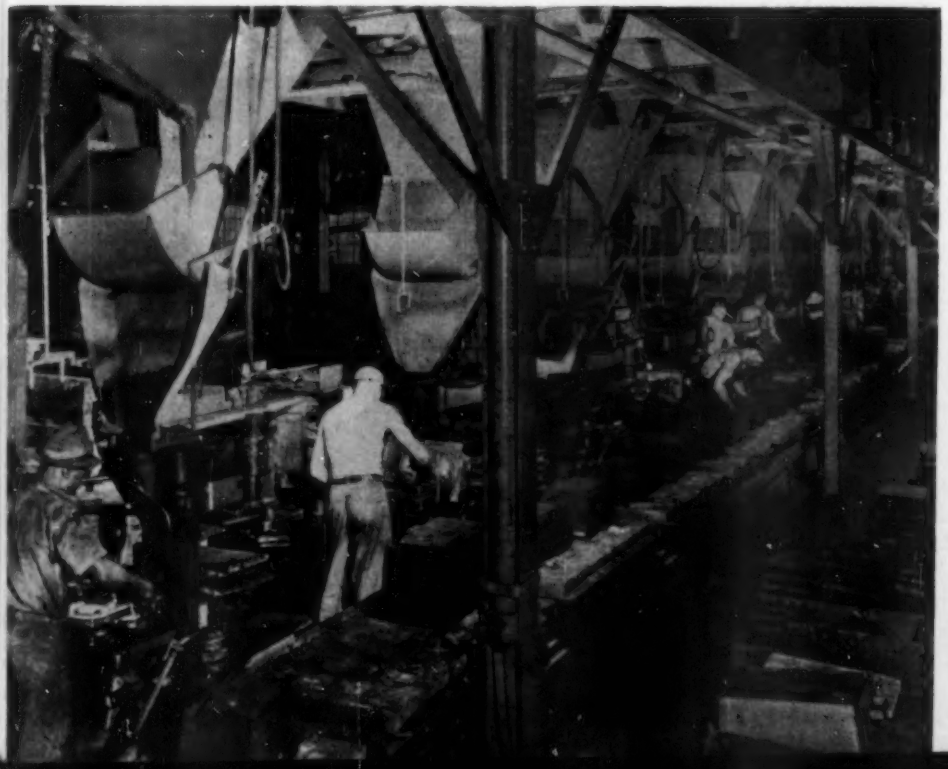


Fig. 3—Typical conveyor line molding. Sand from overhead hoppers is delivered to molding machines whose tables approximate elevation of conveyor trays.

Certain foundry products such as sand and fuel were in a comparatively abundant supply, while pig iron, scrap and metal supplies had to be diverted when necessary from one destination to another. This compelled foundrymen to practice substitution and conservation in such a way that operations were not always economically sound. Some of the technical features of this practice will be dealt with later.

With some Government authorities allocating materials via the War Production Board, and other Government authorities fixing prices through the Office of Price Administration, while taxes, manpower and other management problems rose, the foundrymen had to exercise much versatility to survive. The Government organizations did

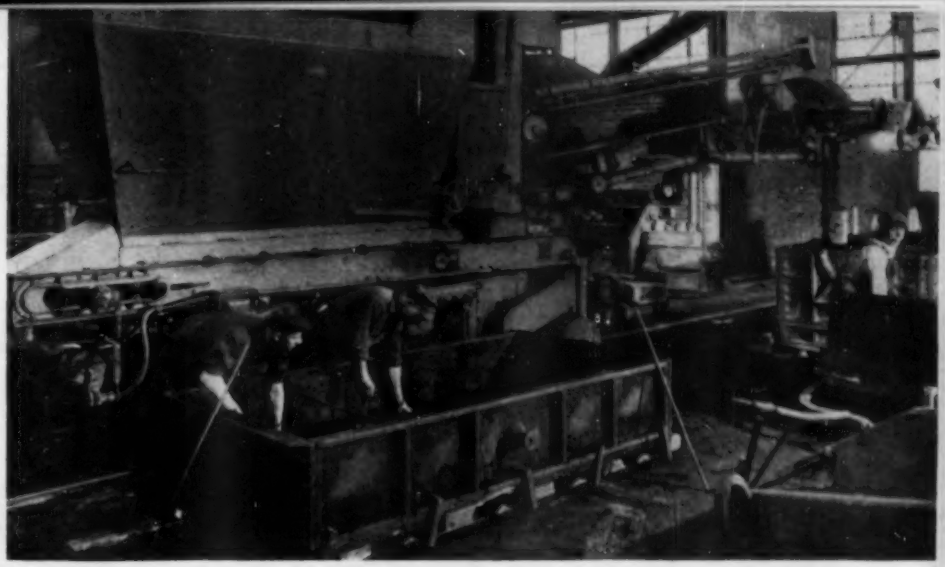


Fig. 4—Carrying its supply of molding sand, the large machine moves along center of shop ramming molds on either side.

an excellent job, the history of which may remain one of the silent but important contributions to the winning of the war.

Ably assisting foundrymen through the difficult readjustment from civilian production to military production were such organizations as the Gray Iron Founders' Society, which worked upon allocations of manpower and materials, cost systematization, safety and wartime security regulations and many other management problems. The American Society for Testing Materials worked up new specifications and necessary wartime adjustments to others. The American Foundrymen's Association acted upon technical matters, many of which are mentioned in the text of this paper and in other articles.

In cooperation with the War Metallurgy Committee of the National Academy of Sciences, an American Foundrymen's Association committee succeeded in assembling data[1] that led to an American Society for Testing Materials specification for cast iron for use at elevated temperatures. Such cooperation was not unusual.

Regional groups, combining practically all of the local units of the different engineering societies, pooled their information and made it available to manufacturers of war material. These groups assembled on short notice for emergency discussions on topics related to war production. In the region of the City of New York, this group was known as the Engineering Societies Committee on War Production.

Sand, Refractory, Mold and Core Materials. Among mold materials in the gray iron foundry, some progress seems to have occurred through the increased use of synthetic mixtures made up from a sand of predetermined grain size and shape with the bond supplied by bentonite or equivalent types of binders. Natural bonded sands continued in favor where supplies and economics and supervisory control were favorable to their use. Cement bonded molding sands continued, at least, to hold their place.

Outstanding developments followed divergent courses. Some supervisors attempted to develop specific sand mixtures to fit exacting requirements, especially where large quantities of similar castings were in production.

In the jobbing shop, where miscellaneous castings and cores had to be made, the interest was directed toward synthetic mixtures bonded with bentonite and cereal binders to make the sand suitable for all types of molding machines. Cores could be made from the same sand mixture, thus adding to the simplification. This provided the simplicity that was needed to relieve supervision without serious injury to the quality of the resulting castings.

The addition of silica flour to molding sands and cores contributed toward producing strengthened mixtures. In some cases, iron filings offered some improvement to core sands.

Molding. Some improvement in the mechanization of sand conditioning and sand conveying occurred, all designed to bring this material more rapidly to the molding machines wherever large volume production was involved. In some cases new installations were made embodying the general principle of bringing in new sand through overhead hoppers and retrieving waste or used sand through underground channels.

A favorite type of mechanized molding might be described as the small and large carousel system. In this construction the small carousel, mounting two or more molding machines, revolved with its crew and equipment and discharged its flasks to the large carousel, which conveyed them to the pouring stations and shake-out. Descriptions of this mechanization have appeared in the trade papers, and Figs. 1 and 2 illustrate some of them.

Molding machines for molds and cores contributed their specific

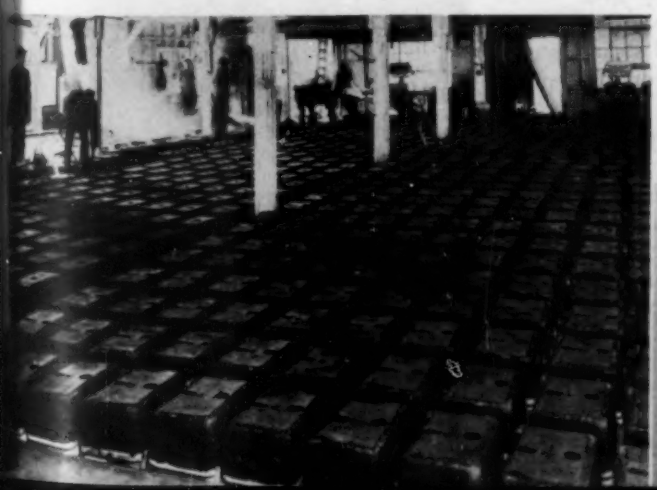
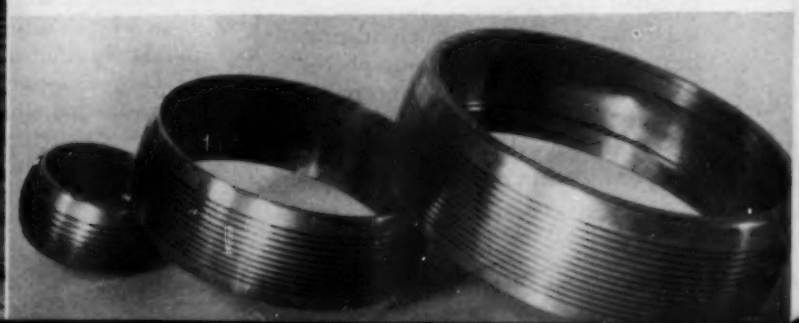


Fig. 5—(left) Squeezer-type machines mold large numbers of nickel-chromium-copper alloyed iron castings.

Fig. 6—(below) Type of castings made in molds shown in Fig. 5. Ball rings for ball and socket joints in aircraft exhaust manifold.



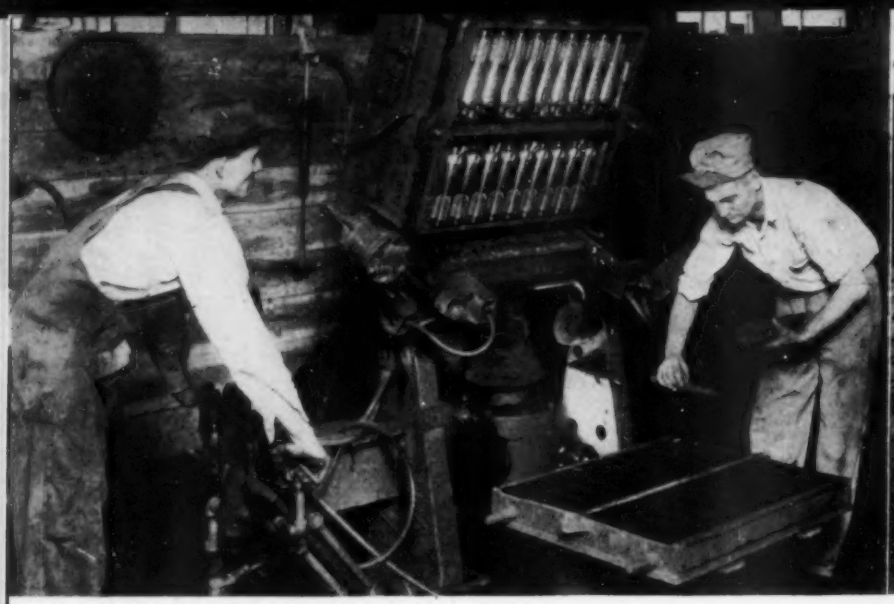


Fig. 7—(above) Machine molding of practice bombs for mass production. Fig. 8 (right) Stacked molds (also inclined).

improvements toward production. There are several varieties, each emphasizing its special merits, but the general trend was toward push-button control of the actuating mechanisms which brought sand (the raw material) to the molds, packed it in place, moved the finished mold along toward the pouring station with a minimum of lifting and handling (Fig. 3). Only one of the largest and one of the smallest types of machines are mentioned in the following text.

Molding Machine Types

Molds for large or irregular shaped castings were made up chiefly with the help of sand slingers (Fig. 4). This type of molding machine varies in detail, but its chief asset is its maneuverability, which enables it to quickly supply large volumes of sand to irregularly shaped molds.

At the other end of the scale, small molding machines of the squeezer type were worked to their accustomed capacity of 250 molds per man per 8 hours, while in exceptional cases even larger numbers were delivered. Figures 5 and 6 illustrate the production of this type in a small foundry engaged in the production of a large number of small castings.

Drying ovens with circulating heat and controlled atmospheres have become typical of everyday foundry equipment. Portable gas- or oil-fired hoods for drying large molds assisted in expediting production. Infra-red lamps have been used successfully for drying molds as they progressed along conveyors to the pouring station.

The unprecedented demand for castings upon certain industries, such as the machine tool builders, required that their foundries multiply production tenfold in some cases. For example, a shop producing 150 tons per month was required to produce 1,500 tons per month. Where men, machines and materials were available to do this task, limitations often occurred in floor space. The problem was solved by stacking the molds one on top of the other as high as it was possible to go and still provide clearance under the cranes for the pouring ladles.

In shops producing small castings such as bombs and grenades, it was common to employ this same principle, which in this case resembled methods used in casting piston rings, radiator sections, etc. Molds were stacked one upon the other with the elevation limited only by the clearance under the roof or crane in cases where large pouring ladles were used, or alternately, to the level to which men could lift the ladles where hand pouring methods were practiced. Illustrations of machine molds of this type and their assembly on the foundry floor appear in Figs. 7, 8 and 9.

Less spectacular but equally versatile methods were employed in jobbing shops where custom-made castings in small numbers were produced. Large castings would be rammed with sand slingers or massive jolt machines capable of handling large flasks. Much time was saved in floor molding by installing permanently level floors or leveling devices in the bottoms of pit or floor molds.

Centrifugal Castings. During the war, the iron foundry taught its associated metal forming industries a number of improvements and it learned a number in return. Centrifugal casting achieved new high stages of accomplishment. Shops which had been accustomed to making centrifugally cast pipe, succeeded in producing alloy steel cylinders for aircraft, hollow steel shafts for marine service, and small diameter, 75 mm. (2.9 in.), pipe, 10 mm. (0.393 in.) thick and 7.5 meters (24.6 ft.) long, made of alloy steel of the 18 per cent chromium-8 per cent nickel or 25 per cent chromium-20 per cent nickel alloy steel and with flanges welded on.

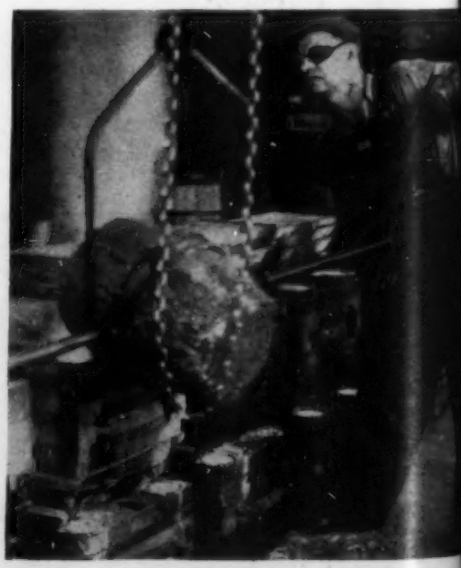


Fig. 9—Pouring nickel bronze in molds stacked two high.

Some of these activities were related to the centrifugal casting of gun tubes of steel whose production had been established long before the war. Vertical spinning machines as well as horizontal spinning machines were developed for various purposes. The nickel - chromium-molybdenum cast iron lining in a steel shell type of casting became an important component in the form of an aircraft brake drum. Figure 10 illustrates a cross-sectional view of this product.

Vertical axis machines were used for casting gear blanks and flywheels, while clusters of castings in the familiar "Christmas-tree" formation (Fig. 14) were produced by the centrifuge casting principle. The scarcity of forging hammers led to the development of centrifuge die cast parts[2] which possessed close dimensional tolerances in addition to high quality. Some of these castings are made in a carousel type of spinning machine in which molds are spaced at regular intervals around a circle, poured from and spun around a central axis rather than the usual practice of spinning castings about their own axis.

The trend toward dimensional accuracy was also accentuated by progress in the application of the "lost wax" process to the production of precision castings. The ability to produce castings which approximate finished dimensions without machining is bound to attract the manufacturer whose products may cost 50 to 100 times more to machine than they do to cast. An accuracy of about 0.001 in. per in. is promised, and a higher order of accuracy may develop with experience in computing algebraically the thermal expansion and pattern-shrinkage of pattern, wax, mold and casting.

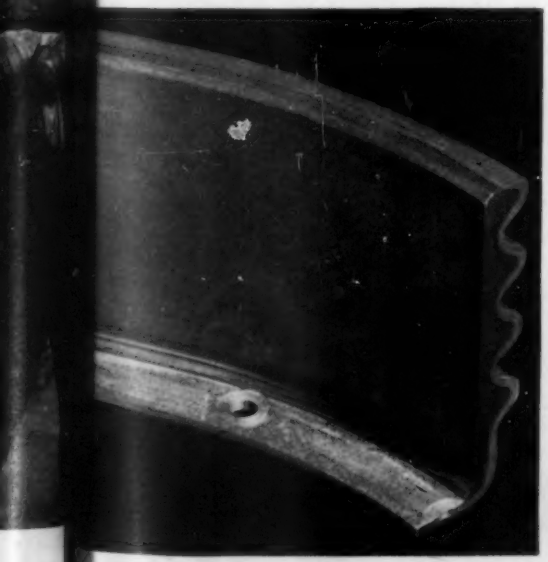


Fig. 10—Cross section of typical centrifuse brake drum showing steel-backed high-carbon nickel-chromium-molybdenum alloy cast iron braking surface. Composition range, per cent, total carbon, 3.70-3.90, silicon, 1.45-1.65, nickel, 1.35-1.55, chromium, 0.30-0.40, molybdenum, 0.30-0.40.

Research upon refractories, facings and binders used in the precision casting process is in progress, and improvements are destined to be rapid. Gating, risering and coring such castings challenges the skill of the foundryman, and mechanical aids to the rapid flow of metal such as centrifugal, vacuum or pressure casting are being developed which will rapidly extend the application of these types of foundry products.

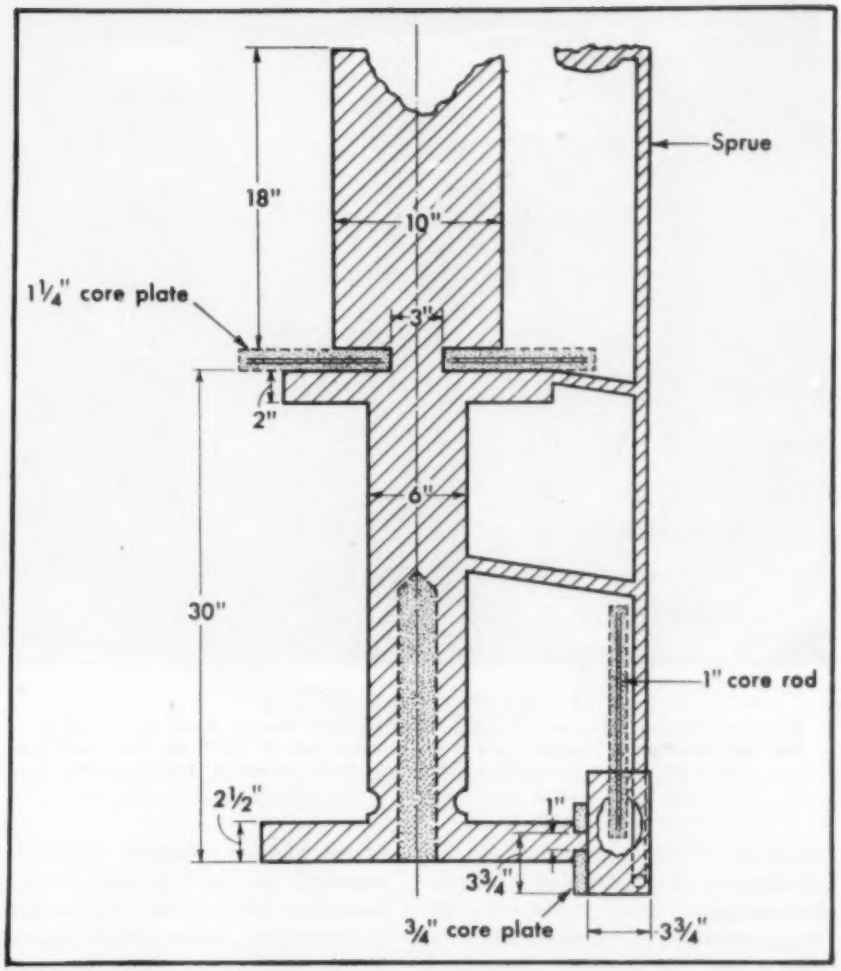


Fig. 11—Sketch showing gating practice for nickel-chromium-copper alloyed casting. Step gates, Williams riser (atmospheric pressure supplied by 1-in. core rod), gating through the riser and knock-off risers. Note relative dimensions and design of risers, riser connections and gating system. Freezing may be traced from thinnest sections and coldest metal to heaviest section and hottest metal in the risers.

Directional Solidification. Directional solidification, embodying old principles but requiring periodic re-examination to stimulate the interest of foundrymen, was applied, re-studied and re-emphasized. The Naval Research Laboratory illustrated and emphasized the fundamental point that castings must be proportioned and gates positioned in a manner that compelled the metal farthest from the risers to solidify first. After that, solidification must progress toward the riser where the hottest metal is located.

Gating, risering, padding, chilling, flowing off, tilting molds, pouring speeds, pouring temperatures, mold and core shrinkages, etc., represent some of the factors studied in the approach toward the objective of producing cast shapes that were as sound and solid as wrought shapes. Figure 11 illustrates the application

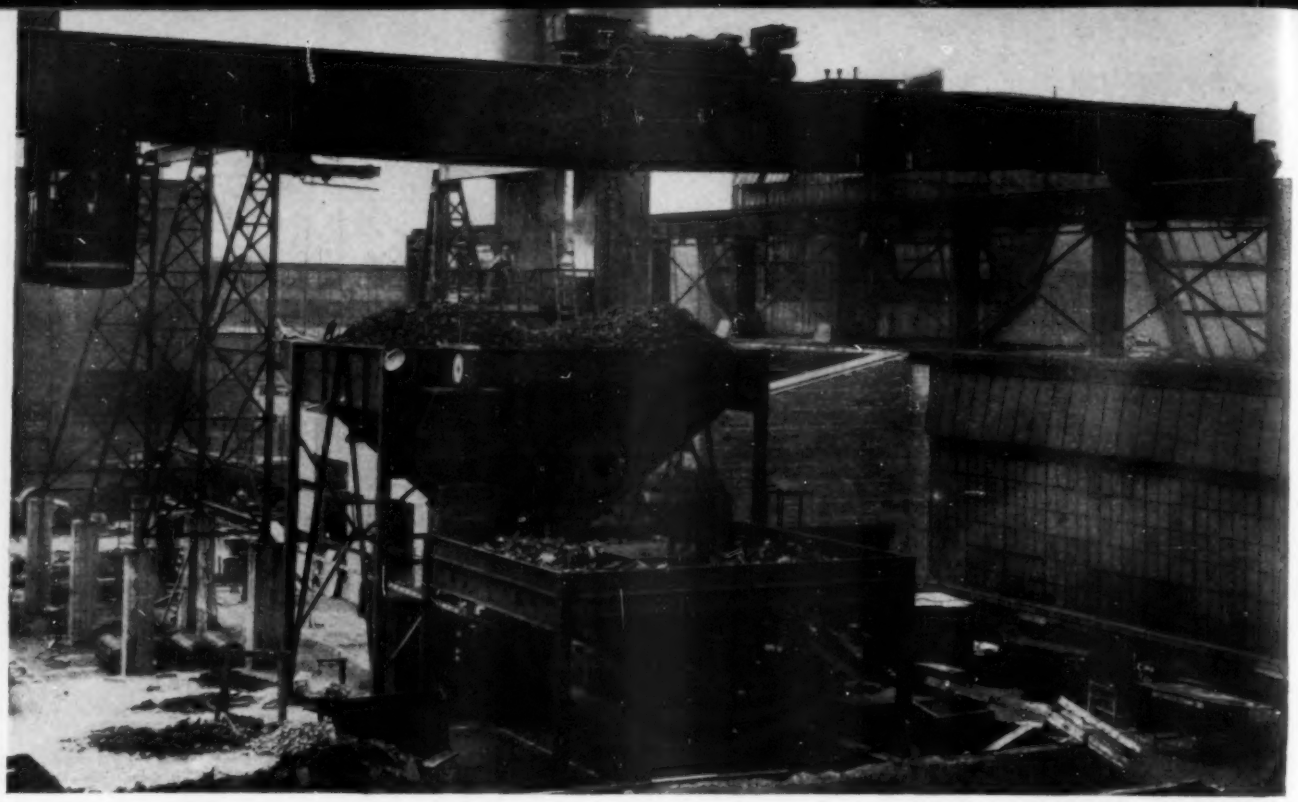


Fig. 12—Typical mechanical charging. Electromagnet handles metal portion of stock from bins to weighing hopper. Scale registers within sight of crane cab. Coke and limestone are added to bucket which follows track to cupola charging hoist.

of some of these principles to the production of commercial castings. Foundrymen were stimulated by these activities, which were also promoted by the Steel Founders' Society.

Dependability in castings was emphasized as worth the extra time and skill required. The soundness of castings for war purposes was not left to chance, but was certified by non-destructive testing via x-ray, gamma ray, etc. The resulting experience has developed a large and expert following.

Metal Melting and Distribution. Cupola practice responded to the demand for larger tonnage and high quality by accommodating a number of readjustments. Conservation of material and manpower produced changes, some of which will remain permanently.

The foundrymen soon learned that the extra capacity obtainable from their cupolas taxed the labor available to the point where production could not be maintained without help from mechanical devices. This led to the application of mechanical charging systems for cupolas. In most cases the charging bucket is filled in the stockyard by a travelling crane employing an electromagnet to handle the metal ingredients.

These are weighed by means of a scale located within sight of the craneman's cab. Coke and limestone are cascaded onto the charge in the bucket from hoppers containing weighing or measuring devices. This operation is usually performed as a second step after the metal charge had been prepared. A third operation employs an electric hoist which picks up the bucket and moves it into the cupola where its contents are dropped.

This procedure had reduced the charging crews in foundry yards from numbers varying from 15 to 30 men, down to 3 or 4. In the course of this change, all of the heavy work of loading, weighing and conveying stock, and the hot work of hand charging which accompanied it, had been eliminated. This innovation operates in several modifications.

Figure 12 illustrates a typical installation. It was introduced in foundries melting more than 50 tons per day, but has become sufficiently attractive for foundries melting as

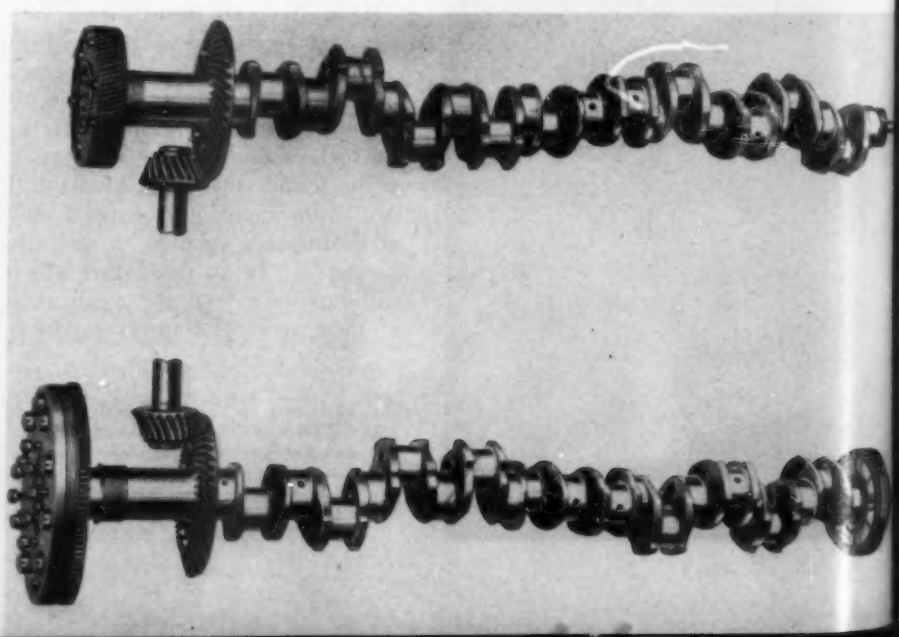


Fig. 13—High strength alloy twin crankshafts for 20-cylinder diesel engine.

little as 10 tons per day. It solved the problem of providing a sufficiently rapid charging rate to accommodate the greater melting rate accompanying the demand for increased production.

Metal removal at the spout presented a less difficult problem. Additional cranes, tramrails, motorized ladle buggies and ladles provided the handling capacity necessary to remove the additional tonnage melted. The maintenance of mixing and transfer ladles and similar equipment was facilitated by improvements in refractories, which included the application of prepared shapes such as ladle bottoms which could be laid into place in a single piece.

Similarly, slag-skimming spouts for ladles and cupola spouts were fitted in many cases with prepared refractory shapes, which saved much time in maintaining or repairing this equipment.

Emphasis on the conservation of alloys and raw materials, including machine shop turnings and sheet metal clippings, led to reclamation practices, many of which will continue in the postwar period. The reclamation of alloys by segregating and classifying machine shop turnings became an important step in alloy conservation. It was claimed that only 10 per cent of the aircraft steel originally melted found its way into the working parts of a plane.

Cupola Charging Materials

Alternating famines in pig iron or scrap or alloys developed experience with a wide range of charging materials, which demonstrated the adaptability to cupola melting of charging stock heretofore considered unsuitable. For example, the melting of briquetted cast iron borings and steel turnings from the machine shops taught the foundryman the need for compressing these materials and limiting the size of the resulting compact within ranges that would assure him of good melting and product control.

Bundles of steel clippings also had to possess a certain measure of density in order to melt well. In addition, it was found that the quantity of such scrap per charge that could be used might be limited by the pressure which the cupola blast system was able to deliver.

The briquetting procedures carried with them the need to recover oil that was introduced in the machine shops, mainly to eliminate the smoke nuisance which accompanied the use of this type of charging stock in the cupola. In some cases, the reclamation of alloys by recovery through briquetted borings caused a higher operating cost which, at the time, was justified in many cases through the need for conservation.

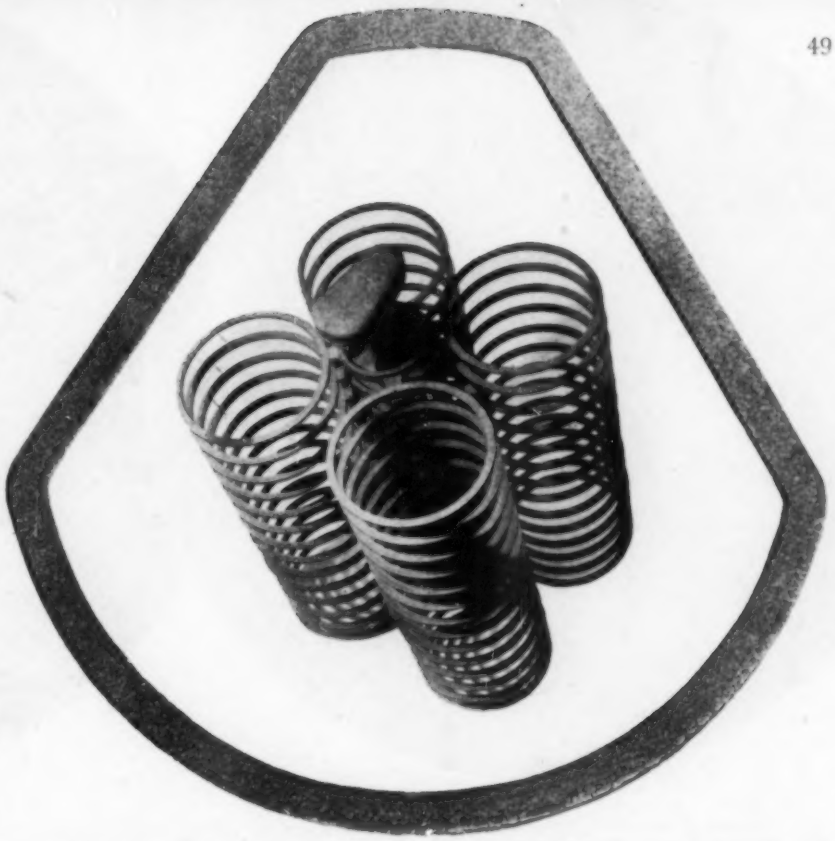


Fig. 14—(inset) Method of casting nickel-chromium-molybdenum alloyed and inoculated iron piston rings. Fig. 15—Type of specimen used to test piston ring iron.

The installation of additional hot blast systems contributed also to a substantial saving in fuel, particularly where shops were melting more than 20 tons of iron per day. In some shops the hot blast systems were used to improve melting temperatures.

While this may not have led to any economy in the use of fuel, it accomplished a more important objective in these shops through providing a hotter iron, which contributed to the production of sound castings and better physical properties. Future developments in hot blast systems may improve efficiency and reduce bulk, thus providing an additional appeal to the smaller tonnage foundries in the problem of saving fuel or improving upon control.

Additional blast humidity control systems were installed principally to improve control and thus improve quality. Foundrymen are conscious of the fact that approximately 1½ tons of air are blown into the cupola for each 2 tons of iron melted, and this volume of air may contain 15 to 30 liters of water, which takes a toll of heat units out of the fuel bed and metal charge. The increased loss in carbon, silicon and manganese attending the use of a humid blast could be eliminated by operating to a standardized humidity of the blast.

Careful research work in the laboratory upon these subjects,[3] when converted to commercial practice, offered foundrymen some measure of the influence of these factors upon the quality of the product or the economy of the process. These details of cupola operation, involving the study of the size and density of the metal and fuel charging stock, accompanied by better control over the temperature, pressure, volume and humidity of the blast, led to substantial improvements in practice which will lead the foundry industry to operate at new high standards in the future.

The restricted availability of high grade charging stock often forced foundrymen to use desulphurizing and other purifying fluxes. In the

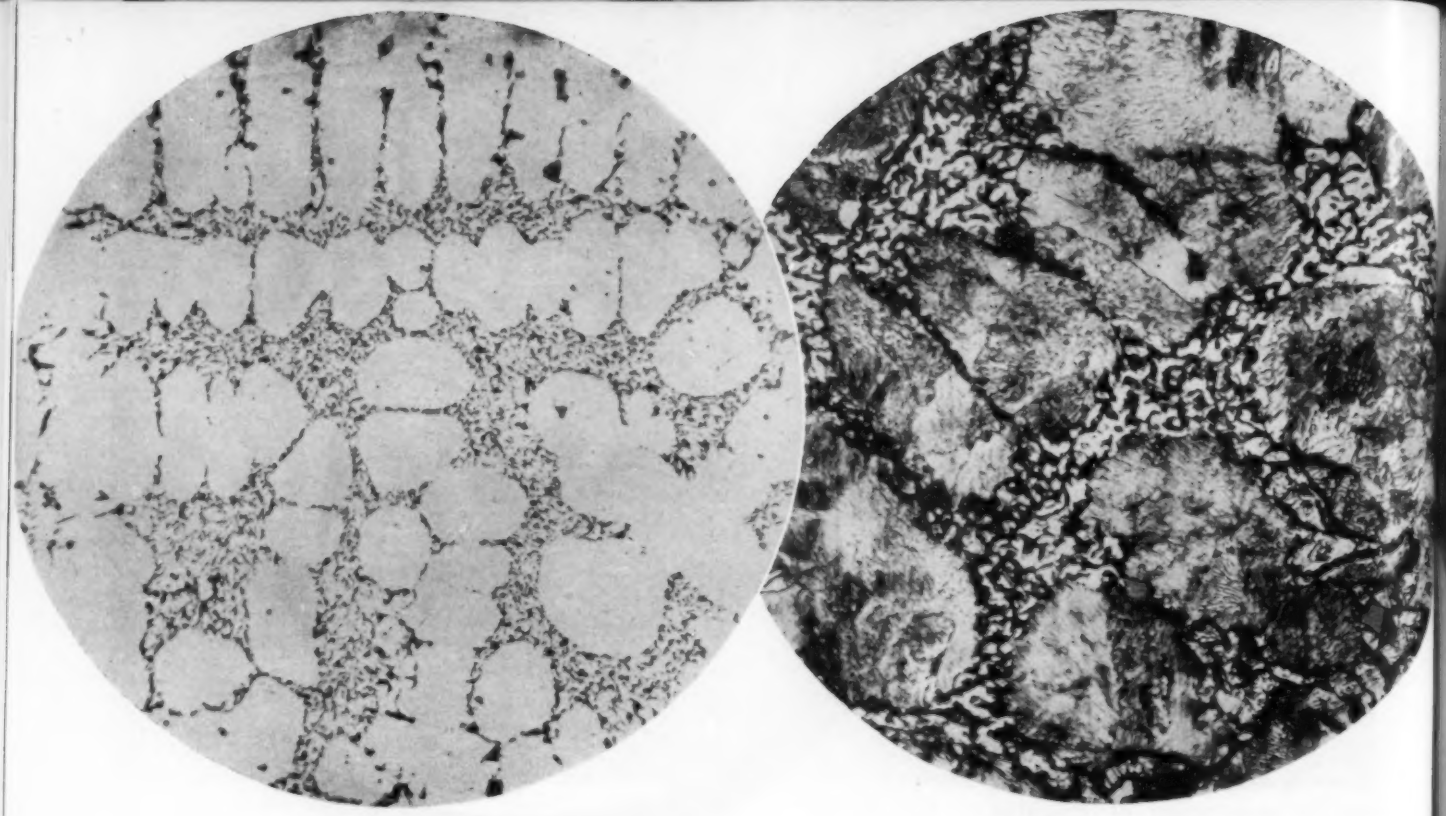


Fig. 16—(above) Photomicrograph of untreated machine tool iron near surface. Unetched, 250X. Fig. 17—(right) Same iron shown in Fig. 16. Etched, 500X.

postwar period, many of the difficulties related to this problem will be eliminated through the selection of better raw materials. The practice of duplexing by employing the electric furnace as a hot metal receiver and metal refiner gained further support. Castings requiring close control over composition or properties lent themselves much more readily to this duplex type of melting.

Weighing and measuring devices for closely controlled furnace and ladle contents were required. Common practice consisted of sampling the cupola metal by making preliminary analyses or chill tests and adjusting the metal in the electric furnace prior to pouring. With this type of control, some of the metal for high strength castings such as the crankshaft, gear, camshaft, and similar shapes could be easily prepared, alloyed up to a level necessary for the casting section and poured into molds, resulting in a product possessing strengths of from 60,000 to 100,000 psi.

Cupola melted irons of this type also were produced in large volumes. They readily exceeded the 60,000 psi. minimum tensile strength, and in special cases they travelled the entire high strength route to values exceeding 80,000 psi. Figure 13 illustrates a difficult crankshaft made from a nickel-chromium molybdenum alloyed metal.

The American Foundrymen's Association and the American Society for Testing Materials' organizations have endeavored to simplify the problem of procurement and production of specification grade material. Two additional important factors have contributed to the ease of producing cast irons of this type: (1) alloys and (2) inoculants.

With the introduction of alloys and inoculants it has become possible for small tonnage jobbing foundries to standardize upon a single semi-steel mixture, containing 40 per cent or more of steel, and from it, by means of alloys and inoculants, produce the entire specification range of No. 20 to No. 60* American Foundrymen's Association and American Society for Testing Materials cast irons.

By this device it is possible for the foundryman to treat a metal mixture of this type at the cupola spout or upon transfer from the mixing ladle by employing varying amounts of alloys and inoculants to suit the specification requirements of different castings. Since the molds for these castings may not all be ready for pouring at one time, the flexibility which the method provides enables the foundryman to treat his standardized mixture over a longer melting interval in the course of which molds are completed and prepared for pouring.

In production foundries handling large quantities of similarly shaped castings, it has been possible with the help of alloys and inoculants to produce very small castings such as individually cast piston rings, for example, to strength levels exceeding 65,000 psi. and keep them machinable as well as in good microstructural condition as regards resistance to wear, by making such castings conform to predetermined types of graphite structure (Figs. 14 and 15, and Tables 1 and 2).

In this connection, again the co-

*Numbers correspond to tensile strength in lb. per sq. in. (psi.), viz:

Iron No.	*Psi.*	*Kg/mm*
20	20,000	14
40	40,000	28
60	60,000	42

Table 1

TYPICAL COMPOSITIONS OF ALLOY IRON PISTON RINGS

	Composition, per cent
Total Carbon	3.50
Silicon	2.78
Manganese	0.61
Nickel	0.92
Molybdenum	1.09
Chromium	0.20
Phosphorus	0.22
Sulphur	0.067

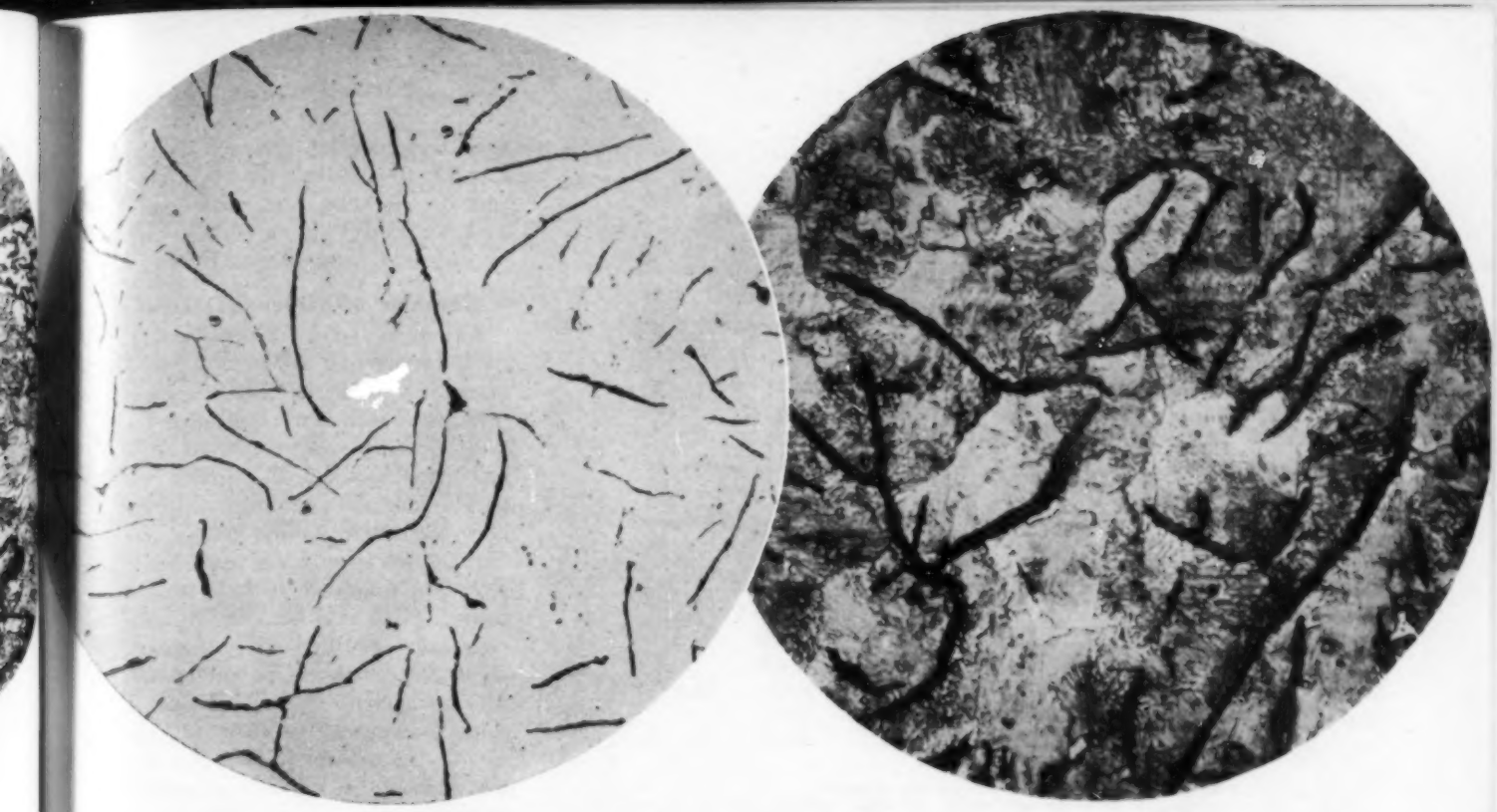


Fig. 18—(left) Photomicrograph of machine tool iron near surface, inoculated with nickel (Type B). Unetched, 250X. Fig. 19—(above) Same as Fig. 18. Etched, 500X.

ordinated activities of the American Foundrymen's Association and the American Society of Testing Materials have assisted in providing a chart classifying the type and size of graphite flakes in cast iron. This map of graphite flake structures has been extremely useful in indicating to both producer and consumer the type of graphite desired.

Mechanism of Inoculation

Inoculation, which had become common practice during the war, is certain to continue as a tool in the hands of the foundryman for eliminating heretofore unexplained variations in the quality of his product. The mechanism of inoculation has been traced to a reaction which, when executed in its proper time and place, forces the crystallization of graphite in the stable system.

Commercial inoculants usually possess a high order of graphitizing power which is supplied through the presence of graphitizing elements plus deoxidizers and degasifiers. Their important function of stabilizing the structure of the graphite leads to the production of a narrower and more dependable range of physical properties for metal of the same composition. Along with this improvement in structure comes an improvement in toughness, machinability, wear resistance and strength.

Inoculants containing alloys, such as nickel, chromium, manganese, molybdenum, titanium or zirconium in addition to silicon, calcium, aluminum and other deoxidizing or degasifying constituents are commercially available and are used for the specific improvements they confer beyond either their alloy contributing influence or their graphite structure control. Table 3, taken from the A.F.A. Alloy Cast Irons Handbook, illustrates commercial types of inoculants.[4]

As previously mentioned, the practice of inoculation has won a large following. Among the wear resisting castings a high percentage are treated with inoculants in the course of production. In a survey of heat resisting applications of cast iron, mentioned in the following, over 40 per cent of the castings for this exacting service had been inoculated.

In certain foundries the entire output is inoculated, and the practice has become important particularly in shops producing automotive, diesel, compressor, hydraulic machinery, machine tool castings and similar wear resisting products.

Figures 16 to 19 illustrate the difference in microstructure of untreated and inoculated machine tool cast irons. The powdery graphite structure may not extend entirely through the thickness of the section, but is prevalent at the working surface, often to a depth of 10 mm. (0.393 in.), which exceeds the amount of metal removed from the castings by machining. In addition to wear-resisting structure, a good inoculant will promote uniformity in structure for irregular sections, and better machinability.

The demand for steel castings exceeded the capacity of steel found-

Table 2

Typical Properties of Cast Irons

	Standard Gray Iron for Piston Rings	*Alloyed Iron*
Tensile Strength, psi	41,200	72,400
Rockwell Hardness	101 (B)	30-C
Elastic Modulus, psi	11.9×10^6	$17.0\text{-}18.0 \times 10^6$
Modulus of Rupture, psi	.....	117,000
Izod Impact* (in.-lb.)	3	5

*Comparative values obtained from breaking 0.14×0.26×3.0-in bars in an in.-lb. Izod test machine.

Table 3

SOME TYPICAL ANALYSES OF LADLE INOCULANTS

Inoculant	Composition, per cent						
	Carbon	Calcium	Chromium	Manganese	Silicon	Titanium	Zirconium
Ca-Metal	.....	100*	.....	.....	.....	.....	.....
Ca-Si	.....	30-35	.....	.....	60-65	.....	.....
Ca-Si-Ti	.....	5-8	.....	.....	45-50	9-11	.....
Cr-Si-Mn-Ti-Ca	.....	1*	38-42	8-11	14-16	1*	.....
		1*	28-32	14-16	15-21	1*	.....
Cr-Si-Mn-Zr (3 Grades)	.....	.....	30-52	5-10	14-35	.....	1-6
Fe-Si ‡							
Graphite	90-100	.....	.....	.....	.....	.....	.....
Mo-Si **	.....	.....	.....	.....	30*	.....	.....
Ni-Si †	.....	.....	.....	.....	30	.....	.....
Si-C	28-46	.....	.....	.....	45-56	.....	.....
	50	.....	.....	.....	42*	.....	.....
Si-Mn	.....	.....	.....	20-25	47-54	.....	.....
Si-Mn-Zr	.....	.....	.....	5-7	60-65	.....	5-7
Si-Ti	.....	.....	.....	.....	20-25	20-27	.....
Si-Zr	.....	.....	.....	.....	47-52	.....	35-40
	.....	.....	.....	.....	39-43	.....	12-15

*Approximate. **60 per cent molybdenum. †60 per cent nickel.
‡Several grades containing 50 to 90 per cent silicon; also silvery pig iron (6 to 20 per cent silicon) and special iron with 5 to 15 per cent silicon. Refer to ALLOY CAST IRONS HANDBOOK, Table 94, p. 231.

ries with the result that high strength cast irons were called upon to fill in where steel could not be procured. This stimulated progress in the production of high strength irons and the cupola production of those possessing tensile strengths up to 100,000 psi., as previously mentioned. Usually strengths exceeding 60,000 psi. were considered satisfactory, and nickel-molybdenum and nickel-chromium-molybdenum types fill most needs and lend themselves as easiest to produce from the control standpoint.

In this connection a demand arose for cast iron to serve at elevated temperatures. For over 30 years the limiting temperature to which cast iron was permitted to work was 450° F. This temperature had been established by authoritative committees operating in behalf of the American Society of Mechanical Engineers.

Under pressure of the war, the War Metallurgy Committee of the National Academy of Sciences conducted a survey[1] of elevated temperature applications which revealed that for cast iron possessing a carbon equivalent of less than 3.9 no failures had occurred in service above 450° F. The carbon equivalent was defined as C + 1/3 Si + 1/3 P = carbon equivalent. The work led to the preparation of a preliminary specification for cast iron of this type.

This work was executed through a joint committee of the American Foundrymen's Association and the American Society for Testing Materials. The preliminary specification provides for gray iron pressure containing castings suitable for temperatures up to 650° F. Details may be found in the American Society for Testing Materials publications. One item in the specification requires that the cast iron possess a strength exceeding 40,000 psi.

An example of the progress that has been made in this direction occurs in the production of paper mill dryer roll castings weighing many tons each. Tensile strengths exceeding 60,000 psi. in Type C (2 in. diameter) bars, and 45,000 psi. in specimens cut from the top and bottom walls of the roll, represent properties obtainable in the high-test nickel-molybdenum alloyed cast iron that is used.

Additional progress occurred with the heat resisting and austenitic types of alloys containing chromium, nickel, copper and molybdenum in substantial amounts. Among the low-alloy irons, chromium additions up to 1 or 2 per cent accompanied by nickel, copper, and molybdenum, have been developed which possess a much greater resistance to scaling and deterioration under conditions such as prevail in the furnaces of oil stills and power plants.

Corrosion and Heat Resistance

Austenitic irons of the nickel-chromium-copper alloy type were extensively used for both corrosion resistance and heat resistance. A large quantity was employed as a ball joint member in aircraft exhaust manifold assemblies (Fig. 6) and somewhat similar uses were made in less spectacular applications requiring resistance to heat or corrosion. Heat and abrasion resisting cast irons of the type containing 28 to 30 per cent of chromium and 1 to 3 per cent of nickel, along with small amounts of molybdenum, also found employment in heat resisting applications as well as in services requiring the high resistance to abrasion.

Among the abrasion resisting compositions, the low alloyed chromium and chromium-nickel types, along with the special types containing 4.5 per cent nickel and 1.5 per cent chromium, found an increasing usage as liners for grinding mills pulverizing the minerals whose end products were essential to the conduct of the war. These alloyed irons, which could deliver from two to four times the performance of unalloyed types, had to take their turn in the matter of availability, which depended upon the government's decision as to whether the alloys were sufficiently abundant to be used for the purpose intended.

Low Expansion Cast Irons

In contrast, 35 per cent nickel cast irons of low expansivity were promptly allocated the alloys they required for such essential purposes as parts for instruments, machine tools, and precision mechanisms requiring dimensional stability throughout changes in temperature.

Very little change occurred in established practices for heat treating cast irons. Since these practices usually require time and manpower in their execution, it was, in general, less difficult to produce the properties desired in the "as cast" condition. The more leisurely schedule at which peacetime operations move may lead toward a wider application of heat treating prac-

tice in developing special properties of cast iron where such a procedure produced them more economically.

Acknowledgments

It might be explained that some of the photographs shown illustrate the principle of the practice described, while actually picturing a scene in a steel or malleable or bronze foundry. For the illustrations used in the paper, the author wishes to acknowledge the courtesies extended by: Chapman Valve Mfg. Co., Indian Orchard, Mass. (Figs. 1 and 4); Belle City Malleable Iron Co., Racine, Wisc. (Figs. 2, 3 and 12); Mir-O-Coll Alloy Co., Los Angeles (Fig. 5); Ryan Aeronautical Co., San Diego, Calif. (Fig. 6); Lufkin Foundry & Machine Co., Lufkin, Tex. (Figs. 7 and 8); Long Beach Brass Foundry Co., Long Beach, Calif. (Fig. 9); Motor Wheel Corp., Lansing, Mich. (Fig. 10); Fairbanks Morse Co., Beloit, Wisc. (Fig. 13); Koppers Co., Inc., American Hammered Piston Ring Div., Baltimore, (Figs. 14 and 15).

In conclusion, the author wishes to express appreciation to his associates in the International Nickel Co. and to friends in the industry for their contributions to the substance of this paper.

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2. Peter Blackwood and John Perkins, "Centrifugal Castings," TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 273-312 (1944).

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Cause and Control

of

Magnesium Alloy Microporosity

• The twenty-fourth in an unbroken series of annual exchange papers — 1922-1945 — from the Institute of British Foundrymen to the American Foundrymen's Association . . . treatment in the present paper of cause and control of microporosity in magnesium alloys attests the value of this broad exchange of knowledge and ideas for the common advancement of the foundry industry.

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Research Manager,
and
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Research Association,
London, England

THE FORM and distribution of porosity in magnesium base alloy castings solidified under controlled conditions have been studied and some comparative tests made on aluminum-base alloys of similar constitution. It is concluded that:

1. The characteristic microporosity in magnesium alloys is due essentially to unfed shrinkage in alloys which solidify over a temperature range.

2. That the presence of gas in magnesium-base alloys causes a marked increase in the amount of microporosity in the casting and does not alter its characteristic form.

3. That owing to their low heat capacity and relatively rapid solidification the temperature distribution in many magnesium-alloy castings tends to be less favorable to progressive feeding.

4. That under the same solidification conditions the strength of unfed castings in magnesium and aluminum alloys is affected to the same extent, but that it is more difficult to ensure correct solidification conditions in magnesium than in aluminum alloys.

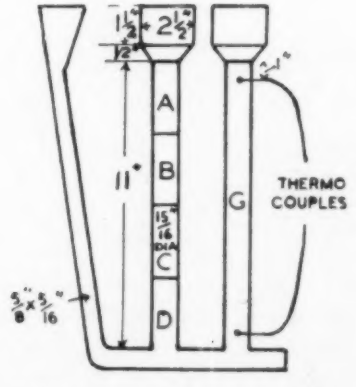


Fig. 1C—Bottom-run vertical bar. Round-section parallel bars, top-fed, showing location of couples and position of A, B, C, D, G bars. Similar bars were made without feeders but with 1 in. dia. downgate and runner and poured at controlled rate through a bush.

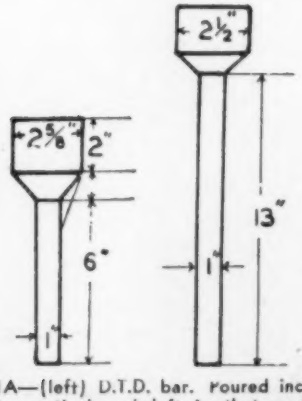


Fig. 1A—(left) D.T.D. bar. Poured inclined 30° to vertical and left in that position.

Fig. 1B—(right) Top run bar with feeder usually too small to give complete feeding. Cast in inclined position.

Foundry technique must be such that the metal is free from gas initially and does not pick up gas by reaction with overheated sand. Running, pouring and gating conditions must be adjusted to ensure progressive solidification from the important parts of the casting toward the risers and feeders.

One of the principal difficulties encountered in making castings in magnesium alloys is the occurrence of a fine form of porosity known as microporosity, and the British Non-Ferrous Metals Research Association has carried out an extensive research to determine the causes and methods of controlling microporosity in magnesium alloy castings. The following paper gives an outline of the results so far obtained. More complete details of the experimental work are given in a paper by W. A. Baker, which has been submitted to the *Journal* of the Institute of Metals.

I. General Lines of Investigation

The investigation has been mainly concerned with sand castings. Castings have been made in various alloys of magnesium, using test castings of different forms. The broad lines of investigation are dealt with as follows:

1. *Metals Used.* All alloys were prepared from pure commercial materials including 99.8 per cent purity magnesium, 99.99+ per cent or 99.5 per cent purity aluminum, 99.99+ purity zinc, 99.8 per cent purity nickel (pellets). Where other constituents were added, these were also of the highest purity obtainable.

2. *Melting.* Alloys were melted in iron crucibles, covered during melting with flux Z, and refined by stirring at a temperature of 1292-1382° F. (700-750° C.) with flux E. Except where otherwise stated, the alloys were superheated to a temperature of 482° F. (250° C.) above the liquidus temperature, i. e., to about 1562-1652° F. (850 to 900° C.) for most alloys. During the superheating the alloys were protected with flux E. Gas-fired melting furnaces were used for most of the melting work done in this investigation.

3. *Mold Materials.* Unless otherwise stated the alloys were cast in a

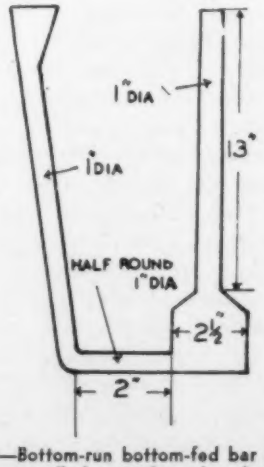


Fig. 1D—Bottom-run bottom-fed bar poured at controlled rate through a bush.

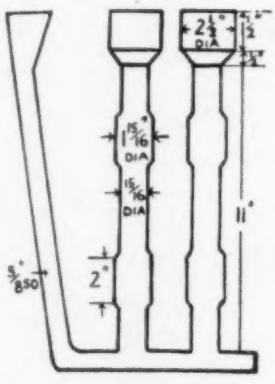


Fig. 1E—Bottom-run round or square-section bulged bars. Similar bars were made with no feeder at top but a 1 in. square downgate, and poured through a bush.

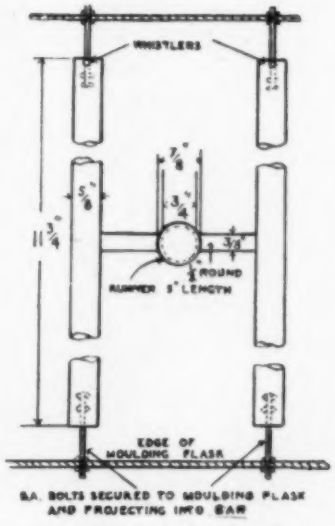


Fig. 1F—Hot-tear test casting.

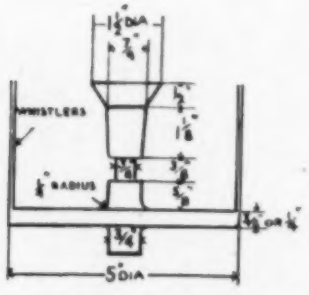


Fig. 1G—Pressure-disk casting. Restricted feeding into boss.

highly permeable silica sand mixture containing 6 per cent of sulphur, 0.5 per cent of boric acid, 4 per cent of bentonite or 5 per cent of no. 1 (a fuller's earth essentially calcium montmorilbonite similar in some respects to American bentonite).

4. *Types of Castings Used.* Several different castings were used; the main types are illustrated in Fig. 1, although some alterations were made in the dimensions during the work.

(a) D.T.D. type bars which in general gave specimens free from porosity and whose properties formed a standard for comparison purposes. This is the form of test bar normally specified in Britain by the Directorate of Technical Development of the British Ministry of Aircraft Production.

(b) A top-run bar with feeder of varying size generally too small to give complete feeding.

(c) A bottom-run vertical bar with a feeder head at the top, termed a conventional bar.

(d) A bottom-run, bottom-fed bar, termed an inverted bar.

(e) A bottom-run bulged bar of either circular or rectangular cross-section, with or without a feeder head at the top.

(f) A hot-tear test casting in which horizontally cast bars were cast around small insert bolts, which were secured to the molding flask by means of a nut. The nut could be slackened back to vary the degree of restraint applied to the bar during solidification.

(g) A pressure-disk casting. A flat disk with a central boss tested up to 200 psi. air pressure in machined and unmachined condition.

Except for the D.T.D. bar, all of the foregoing castings were not fully fed, and were designed for study of the effects of varying distribution of shrinkage porosity. A few castings were also made in chill molds, which were lowered into molten lead-tin alloys held at a controlled temperature.

5. *Methods of Examination.* The castings produced were examined in the following ways:

(a) Density. The densities of the castings or sections cut from castings were determined, from which the proportion of voids in the metal could be calculated. The specific gravity of a casting that had not been properly fed was compared with that of a D.T.D. bar. That the D.T.D. bars usually gave the maximum density of the alloys was proved by microscopic examination, which showed them to be free from porosity, and by the fact that the densities were the same as those of sound chill-cast blocks.

(b) Mechanical Tests. Test pieces were cut from various parts of the castings and tested in tension to show the effect of a given amount of porosity on the strength of the material. The strengths were expressed as percentages of those of sound D.T.D. bars poured from the same melt.

(c) X-Ray Examination. Most of the castings were radiographed, from which the occurrence of streaks of porosity, or localized patches of porosity, could be seen.

(d) Micrographic Examination. Microsections were prepared from various portions of the casting. These served to show the form and distribution of porosity.

Flux Composition*

	Per Cent	
	Flux Z	*Flux E*
$MgCl_2$	11	34
$CaCl_2$	42	15
NaCl	27	9.5
KCl	18	7
MgO	—	10.5
CaF_2	—	18

*British Patents Nos. 539023, 561748, 539024, 562597 and 562636 may be consulted for the compositional range of these fluxes.

II. Porosity Form and Distribution

The form of porosity met with in magnesium-base alloys differs in certain respects from that normally found in other cast metals, and the following terms are used throughout this paper to define particular types of porosity.

1. *Microporosity.* This means finely distributed porosity occurring around the grain boundaries. Typi-

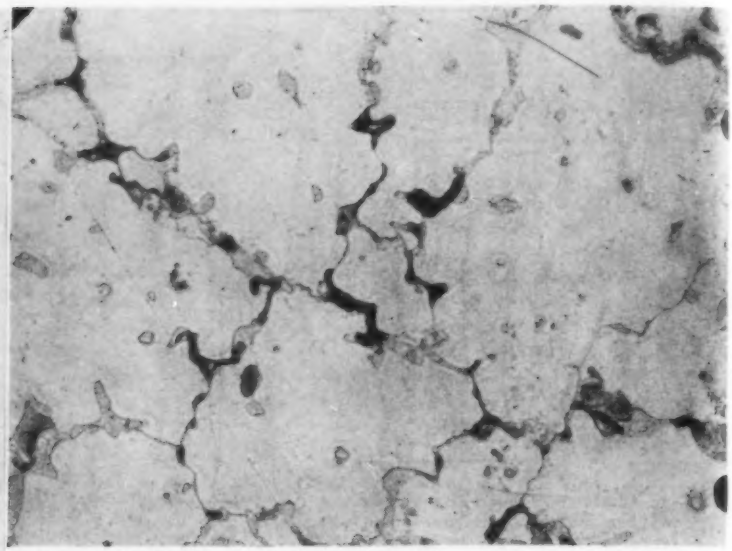


Fig. 2—(left) A typical shallow layer of porosity in a sand casting (partially solution heat treated 93/7 Mg-Al). 40X. Fig. 3—(above) Showing interdendritic fissures. 250X.

cal examples are shown in Figs. 2 and 3. This intercrystalline porosity is not, however, peculiar to magnesium-base alloys, although, since most magnesium alloys are finer grained than other cast materials, e. g., aluminum-base alloys, the porosity is finer. As in many other nonferrous alloys, intergranular or microporosity is shown up as discolorations on fractured castings. It is most pronounced on alloys fractured after heat treatment, the color varying from light straw to almost black.

2. *Layer Porosity.* A particular form of porosity, peculiar to magnesium alloys, shows up on radiographs as dark streaks in sand castings (Fig. 4). Under the microscope these streaks show up as strings of porosity, as shown in Fig. 5. For want of a better description, this type of porosity has been called layer porosity throughout the work, and means porosity appearing as small intercrystalline cavities in patches shallow in depth and of relatively large area.

The layers are at right angles to the wall of sand castings. X-rays only reveal this porosity when the layers lie in the same plane as the x-ray beams. That is one of the reasons why in practice it is necessary to take a large number of x-ray shots in different directions, to be certain that any casting is free from layer porosity.

3. *Intense Concentrations of Porosity.* A patch of porosity is often concentrated at one part of a casting. This form of porosity is common to most cast alloys, and it has the most serious effect on strength. In a radiograph it shows up as a formless mass of porosity, and is independent of the direction of the x-ray beam. Fig. 6 is a photomicrograph showing an intense concentration of porosity in a magnesium alloy. It commonly occurs in that part of an unfed casting which is the last to solidify.

4. *Secondary Pipe.* This takes the form of a single cavity situated at the last part of the casting to solidify. It is found in materials which solidify with little or no freezing range, i. e., pure metals and eutectic alloys. A typical example of a secondary pipe in a eutectic aluminum-magnesium alloy is shown by the photograph in Fig. 7.

5. *Annular Porosity.* This is a defect which appears to be much more pronounced in magnesium-base alloys than in others. It appears in cylindrical chill castings in which an annulus of porosity is found at a distance from the chill face. The external skin of the chill casting is perfectly sound and the internal portion is relatively sound. In many cases the annulus of porosity is resolved into a large number of adjacent small layers normal to the mold wall. A similar type of porosity is also seen in sand castings poured at low temperatures.

III. Effect of Gas

When gas is given off from a metal during solidification, a portion of it is almost invariably trapped inside the casting, where it forms cavities. When the gas comes off while most of the metal is still liquid, the cavities tend to be spheroidal, since the pressure of the gas is greater than that of the atmosphere and the head of still liquid metal,

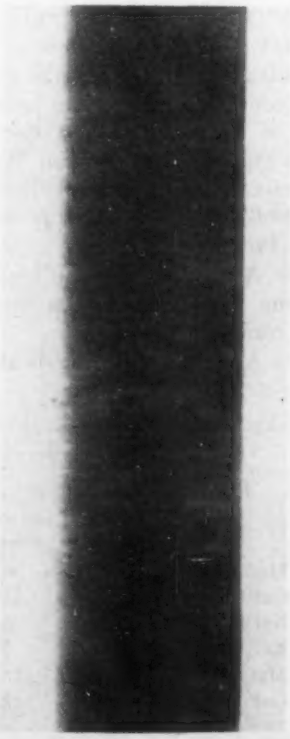


Fig. 4—Layer porosity shown by x-ray

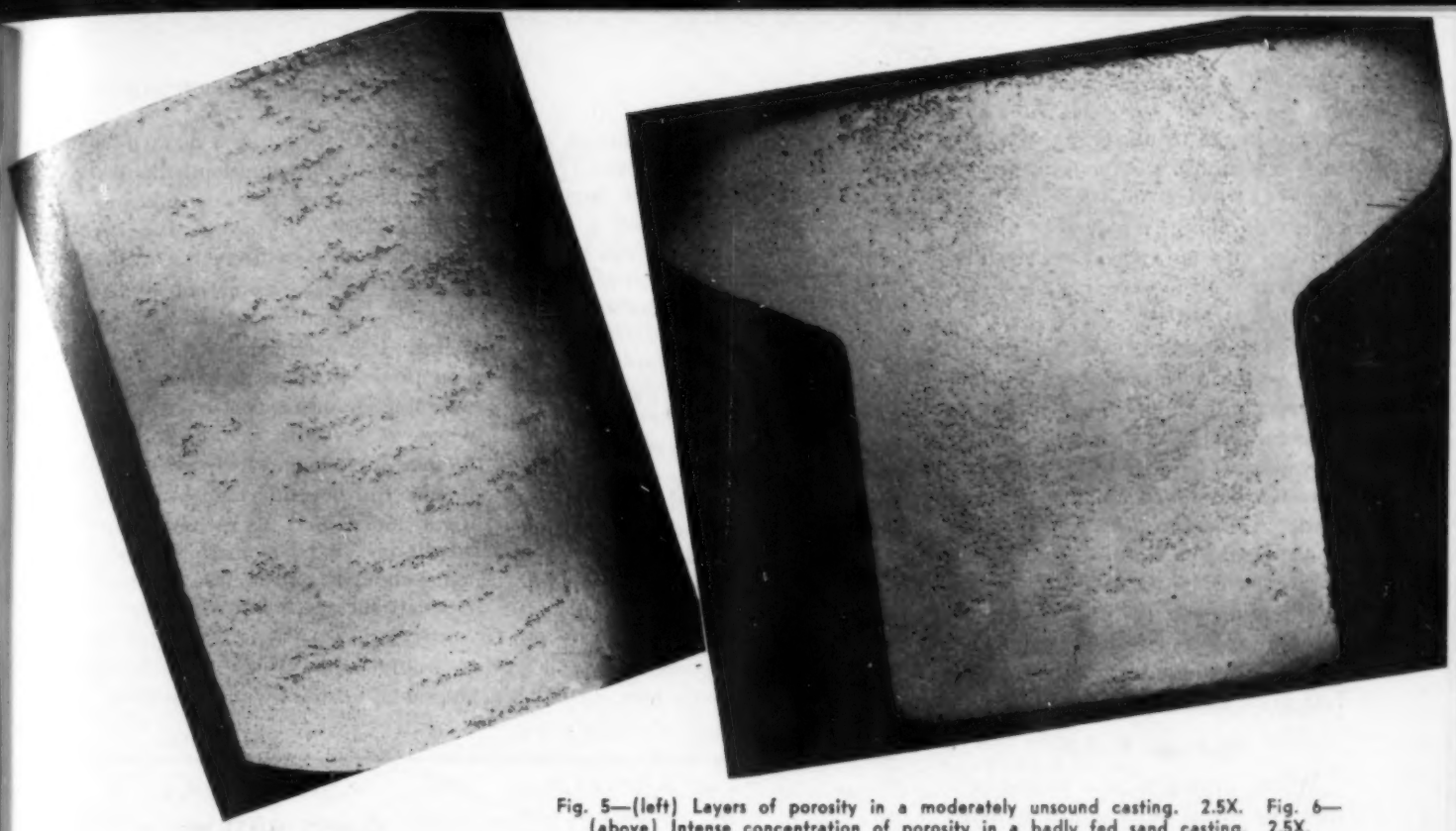


Fig. 5—(left) Layers of porosity in a moderately unsound casting. 2.5X. Fig. 6—(above) Intense concentration of porosity in a badly fed sand casting. 2.5X.

but if most of the metal has solidified before the gas comes off, it will force the still liquid metal from between dendrites that have solidified.

In the complete absence of gas a shrinkage cavity would be a vacuum, and hence even the smallest amount of gas allows cavities to form more easily as a result of the shrinkage of the solidifying metal. It follows that there is no sharp distinction between gas and shrinkage cavities, and it is impossible by merely looking at a cavity between the grains of a metal to say to what extent gas has played a part in its formation.

However, if the metal is allowed to solidify under reduced pressure, the effects of gas are exaggerated and one can estimate whether it is likely to play an important part in a casting solidifying under normal atmospheric pressure.

The possibility that porosity in magnesium-base alloys might be mainly due to gas given off from the metal was one of the first points to be investigated. An outline of the experimental work on this subject follows.

1. *Test for the Presence of Gas.* The test used in this work is illustrated in Fig. 8. A sample of the molten metal is scooped out of the pot into a small, thin-walled iron crucible, which is held in molten metal long enough to reach the same temperature as the melt. The crucible is then transferred to a vessel (with a glass window for observation) which is connected to a large reservoir, which has previously been pumped out to a low pressure.

On connecting the evacuated reservoir with the vessel in which the crucible is placed, the pressure falls to about 60 mm. of mercury. The metal is carefully observed during solidification, and when the sample has solidified it is cut up and examined if necessary. If the metal contains gas, bubbles of gas can be seen rising to the surface while the metal solidifies, and the small ingot, when solid, shows blowholes, as illustrated in Fig. 9.

2. *Experimental Work.* The appropriate gas was bubbled through the molten metal for varying periods before casting. Some tests were made using sulphur dioxide, carbon dioxide and carbon monoxide, but most of the work was done with hydrogen. A magnesium-7 per cent aluminum alloy was used, and the following test castings made:

D.T.D. bars (Fig. 1 A), including some with 1½ in. diameter head.

Up-run bars but without a feeder head, and with runner 11 in. long and of 1-in. diameter (Fig. 1 C).

3. *Results.* No gas unsoundness was found after treatment with sulphur dioxide, carbon dioxide and carbon monoxide, although considerable drossing occurred on treatment with the oxides of carbon.

Melts made from virgin materials or from scrap which had been in storage for only a short time under reasonably good storage conditions gave only slightly gassy melts. Metal which had been in storage for some time, particularly that which had corroded, was gassy, but gas could

Fig. 7—Secondary pipe in a eutectic aluminum-magnesium alloy. 1X.

be driven off by heating the metal to a temperature of about 680° F. (350° C.) for 16 hr. before melting, and could also be removed by allowing the molten metal to solidify, whereupon all the gas was given off, and then remelting.

This procedure, well known in ordinary foundry practice, is known as presolidification. Gas could also be removed by chlorine treatment. However, it was found that some porosity developed in the castings made in the top-poured bars with small heads and in up-run 11-in. bars, even when the melt was shown by the test previously described to be substantially free from gas, but no porosity was found in gas-free metal cast in D.T.D. bars (Fig. 1A).

Hydrogen Porosity

When hydrogen was introduced into the metal before casting some porosity was found in the D.T.D. bars, and the amount of porosity in the other bars increased with a corresponding decrease in strength. As more hydrogen was introduced into the metal, so the amount of porosity in all the bars increased and the strength decreased. However, the form of the porosity was not altered by the presence of gas.

4. *Possible Gas Pick-Up from the Mold.* The foregoing tests were carried out on the assumption that the only gas given off on solidification would be that gas dissolved in the molten metal before casting. However, recent work by the association has shown that many non-ferrous metals pick up hydrogen by reaction with moisture present in sand molds, and even metal which before casting was shown to be free from gas sometimes gave porous sand castings.

A few tests were made to see if magnesium-base alloys picked up gas from molds. Some castings were made in the normal sand mixture, some using Red Mansfield sands (a naturally bonded fine sand containing 4 to 5 per cent of water and with relatively low permeability, e. g., 20 to 30 A.F.A.), uninhibited and partially dried by heating for an hour at 212° F. (100° C.), and others in Red Mansfield sand, uninhibited but thoroughly baked at 1652° F. (900° C.). (This high-temperature baking had been found necessary in other work to eliminate gas pick-up with phosphor bronze.)*

The metal burnt in the partially dried Mansfield sand, and a great deal of porosity, which was of the usual layer form, was found in the bars. However, no porosity was found in bars cast in the inhibited green sand or in the Mansfield sand baked at 1652° F. (900° C.), although in the latter there was considerable penetration of the metal into the sand.

These tests showed that magnesium-base alloys can absorb gas from wet sand molds, although the presence of sulphur in the sand appeared to be sufficient to prevent appreciable gas pick-up. However, even in inhibited molds it is possible that some gas pick-up may occur by reaction between the metal and moisture in the mold, particularly in overheated parts. Fractures through runners and ingates are often badly discolored in the outer layers, suggesting some reaction with the mold atmosphere.

5. *Conclusions.* 1. Gas is not the primary cause of porosity in magnesium castings, since porosity has been found to develop in material which has been tested and shown to be free from gas liable to be evolved on solidification and when precautions were taken to avoid regassing in the mold.

2. The presence of gas in magnesium-base alloys causes a marked increase in the amount of microporosity in the casting and does not alter its characteristic form, i. e., layers of porosity in sand castings.

3. Gas in magnesium alloys may arise in practice from corroded metal. It is assumed that the corrosion products carry with them considerable quantities of moisture which reacts with the metal when molten, introducing hydrogen. The danger can be minimized by storing ingot metal and scrap under dry conditions, or by heating the metal long enough to dry the moisture from its surface before charging.

4. Gas can be easily removed by presolidification, i. e., by allowing the metal to solidify and remelting.

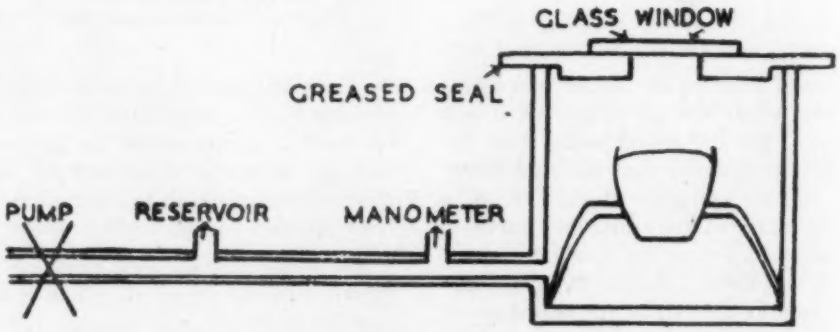


Fig. 8—Illustration of the test for the presence of gas.

IV. Effect of Alloy Constitution

It is well known in the trade that certain magnesium alloys are more prone to microporosity than others. This is not surprising, since it is well known that the form and amount of porosity in other non-ferrous metal castings depend on their constitution. One of the most important factors governing distribution of porosity is the freezing range of the metal, i. e., the temperature range through which the alloy solidifies.

Pure metal and eutectic alloys have no freezing range, but most alloys solidify over an appreciable temperature range. In a simple alloy system, such as aluminum-magnesium, the freezing range can be altered by altering the proportions of the two alloying constituents.

In addition to the freezing range of the material the relative proportion of the metal which solidifies at

*W. A. Baker, F. C. Child and W. H. Glaisher, "The Effect of Shrinkage and Gas Porosity on the Pressure Tightness and Mechanical Properties of Bronze Sand Castings," *Journal*, Institute of Metals, vol. 70, pp. 373-406 (1944).

different temperatures is important. For instance, in some alloys nearly all of the metal solidifies at quite a high temperature and a small amount of liquid remains at the end, and does not solidify until at a much lower temperature.

In other alloys a large proportion solidifies at the lowest temperature. In general, the way in which an alloy solidifies determines the form and distribution of the shrinkage porosity, which is bound to occur unless the casting is completely fed.

1. *Experimental Work.* To study the effect of constitutional change the magnesium-aluminum system was used, and alloys were made containing 2.5, 5, 10, 20 and 32 per cent of aluminum, with freezing ranges varying from 392° F. (200° C.) to 32° F. (0° C.).

Freezing Ranges

It should be kept in mind that the freezing ranges of the alloys are not necessarily those given by the equilibrium diagram, since solidification in a sand casting does not take place under equilibrium conditions.

In this work some of the alloy melts were not superheated, so that a comparison was made between castings with different grain size. However, it should be noted that even in the castings described as coarse-grained the grain size was smaller than that normally found in most other commercial casting alloys, including aluminum alloys.

Test bars used included D.T.D. bars (Fig 1 A), up-run bars 12 in. long (Fig. 1 C), disk castings (Fig. 1 G) and hot-tear tests (Fig. 1 F).

2. *Results.* The results obtained showed that the amount of porosity, as judged by density measurements, did not vary much with the constitution of the alloy, and that microporosity was liable to develop in any magnesium-base alloy which solidifies over an appreciable freezing range and which is not properly fed.

X-ray examination showed typical layers of porosity in both the fine and coarser-grained castings, but the eutectic alloy in each case showed secondary pipe with no layers of porosity. In the 20 per cent alloy also, the porosity tended to concentrate in the center and was intermediate between typical layer porosity shown by the other alloys and the secondary pipe shown by the eutectic alloy.

Properties of Alloys

The eutectic alloy was extremely brittle, and the tensile properties of the 20 per cent alloy were, in general, rather poor. However, there was little to choose between the properties of the other alloys in the coarser-grained castings, but in the fine-grained superheated castings the maximum tensile strength was obtained with the 5 per cent alloy, and in each case was higher than the corresponding strength with the coarser-grained material. This applied both to the D.T.D. bars and the up-run bar.

None of the fine-grained disk castings leaked in the unmachined condition, although some leaked on machining. However, the pressure disks made in the coarse-grained material were much more liable to leak, and in some cases showed cracks around the boss. The finer-grained castings usually showed surface shrinks rather than cracks. The behavior in the pressure-disk test was explained by the results from the hot-tear test, which showed more failures in the coarser than in the fine-grained material.

With a fine-grained material the surface of the casting during solidification consists of a large number of very small crystals suspended in a liquid, and this tends to collapse as a whole as the casting shrinks. However, with a coarser-grained material there is a greater tendency for cracks to form between the grains while the material is solidifying, because the larger crystals rapidly form a coherent mass which cannot collapse as a whole.

Grain Size Effect

Poor resistance to pressure tightness and to hot tearing to some extent therefore go hand in hand, and are controlled, at least in part, by the grain size of the casting. With comparable grain size, the alloys of low aluminum content (e.g., 2.5 and 5 per cent) were more prone to hot-tear and to give defective disk castings than those of higher aluminum content (e. g., 10 and 20 per cent), and this can be explained on similar lines.

In alloys of low aluminum content, most of the metal freezes in the upper part of the freezing range and the interlocking crystals formed are surrounded by thin films of low-melting-point metal. The contraction of the primary crystals during cooling in the lower part of the freezing range tends to pull them apart and produce hot tears, the intercrystalline films of liquid having negligible strength.

In alloys of higher aluminum content, there is a relatively large proportion of liquid metal remaining liquid down to the solidus temperature, and the contraction of the primary crystals is accommodated by feeding of this eutectic liquid or, in some cases, by feeding of the whole mass of small primaries and eutectic.

V. Mode of Solidification of Magnesium and Aluminum-Base Alloys

The work described in the following paragraphs was carried out in an endeavor to correlate the manner in which magnesium alloys solidify with the types of porosity found in them. At this stage it is worth while pointing out some essential differences between magnesium and other non-ferrous metals. Magnesium is by far the lightest of the commercially used metals, aluminum being the next. Magnesium differs from other commercial used metals, except zinc, in crystallizing in the hexagonal system; most other metals are cubic.

Another striking difference between magnesium and most other non-ferrous metals is in the low heat capacity of magnesium. Much less heat is required to melt a given volume of magnesium than for any other metal because of the low specific heat and latent heat per unit volume. Magnesium will therefore solidify much more quickly than any other commercial metal when cast into the same type of mold. Figures showing the density and thermal properties per unit volume of magnesium as compared with other metals are given in Table 1.

1. *Alloys Tested and Types of Castings Used.* A large variety of alloys were tested, including aluminum-base alloys as well as magnesium-base alloys. The alloys were chosen to have similar constitution and freezing range. All the types of castings described in the introductory section were used.

2. *Methods of Modifying Solidification Rates.* As already indicated,

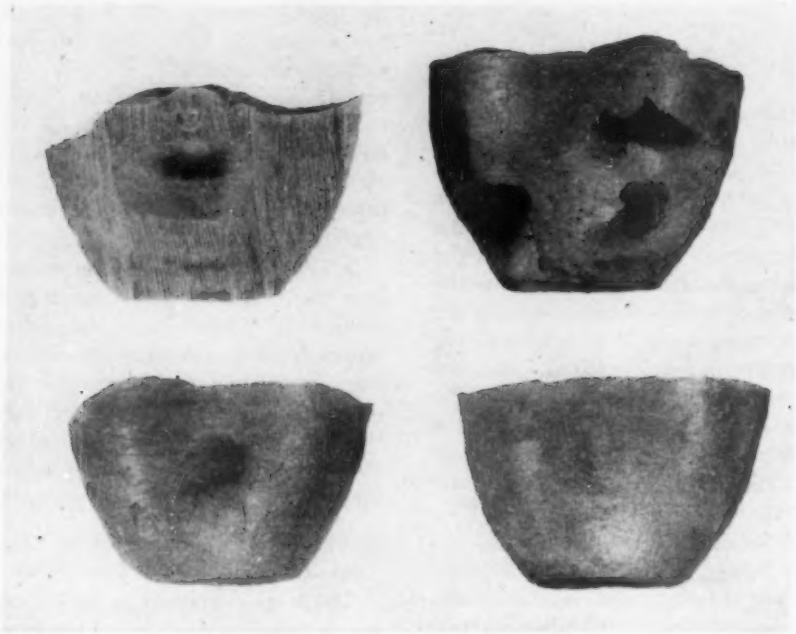


Fig. 9—Examples of ingots solidified under reduced pressure. IX.

magnesium-base alloys will, under comparable conditions of cooling, solidify much more rapidly than aluminum-base alloys. It became necessary therefore to find out what part this relatively rapid solidification rate played in determining the distribution of porosity.

Castings of similar form in both magnesium and aluminum-base alloys were therefore cast in such a way as to give comparable solidification rates. For example, the rate of solidification of a metal can be delayed by using a high casting temperature. This results in excessive heat being introduced into the metal in the mold, and consequently the casting takes longer to solidify.

One method used to lower the solidification rate of magnesium-base alloys was to use a high casting temperature. However, a small amount of calcium was added to prevent burning in alloys cast at high temperature, preliminary tests having shown that calcium additions had no significant effect in solidification behavior or porosity.

Another method adopted was to preheat the mold before casting. This slowed down the rate at which heat was taken away from the metal by the mold and again resulted in a slower rate of solidification. The solidification rate of aluminum-base alloys was increased by introducing uniformly spaced chills into the mold.

3. *Measurement of Temperature Gradient during Solidification.* In some of the test castings made, particularly those of vertical up-run bars (Fig. 1 C), thermocouples were placed at the top and bottom of the castings and records were taken of the temperature during their solidification. From these records curves were drawn showing temperature changes with time.

In most cases it was found that the temperature at the top of the bar was lower than at the bottom when the mold was first filled. However, as the metal solidified, the temperature difference between the top and bottom altered, and Figs. 10 and 11 are typical examples of the type of curve obtained.

When the temperature at the top of the casting was lower than at the bottom, as in the early stages of solidification of the casting to which Fig. 10 refers, solidification would proceed more rapidly at the top. In this case the feeder head was at the top, and during the early stages of solidification feeding from the feeder head downward would be hindered.

The ideal temperature distribution would be that the top of the casting near the feeder was always hotter than the lower part, so that feeding proceeded downward while solidification progresses upward. By comparing the areas "ABC" in Fig. 10 with the area "CDE," one can obtain an indication of the amount by which the temperature gradients during solidification of the casting were unfavorable.

In the example given in Fig. 10 area "ABC" is about one-third of that of "CDE," and the strength of the casting was only 50 per cent of that of a fully fed D.T.D. bar. In the casting to which Fig. 11 refers the temperature gradients were favorable during almost all of the time that the casting was solidifying. In this case the strength of the casting was 84 per cent of that of a fully fed D.T.D. bar.

4. *Mechanical Tests.* Test pieces were cut from various sections (A, B, C and D) of the bar, as indicated in Fig. 1C, and also on a complete bar (G). Density determinations were also made on the various sections of the bar.

5. *Results.* The total amount of porosity found in aluminum alloys, judged by density, was in every case more than that found in magnesium alloys under similar solidification conditions. The tensile strengths of castings which were not fully fed were about the same in both magnesium- and aluminum-base alloys, provided that the conditions of solidification were similar. For a given amount of porosity, as judged by density measurements, the effect on the strength of magnesium alloys was greater than for aluminum alloys.

When bars in aluminum- and magnesium-base alloys were cast in green sand molds of the same dimensions, it was found that the unfavorable heat distribution during solidifi-

Table 1

THERMAL PROPERTIES PER UNIT VOLUME OF MAGNESIUM COMPARED WITH OTHER METALS

Metal	*Specific Gravity*	*Mean Specific Heat cal./cm.³/°C.*		*Latent Heat of Fusion*
		Solid	*Liquid*	
Magnesium	1.8	0.50	0.54	90
Aluminum	2.7	0.68	0.70	250
Copper	8.9	0.89	1.06	440
Iron	7.8	1.25	1.34	500

cation was very much greater in the case of magnesium alloys than in aluminum alloys, but when conditions of cooling were adjusted (either by preheating the mold or casting at a higher temperature for magnesium alloys, or introducing chills into the sand for the aluminum alloys), the relative strength of the two materials was approximately the same.

By relative strength is meant the strength in the unfed casting as a percentage of the strength of fully fed D.T.D. bars. Typical figures are given in Table 2, which includes a column headed "solidification factor," which is derived from curves as illustrated in Figs. 10 and 11.

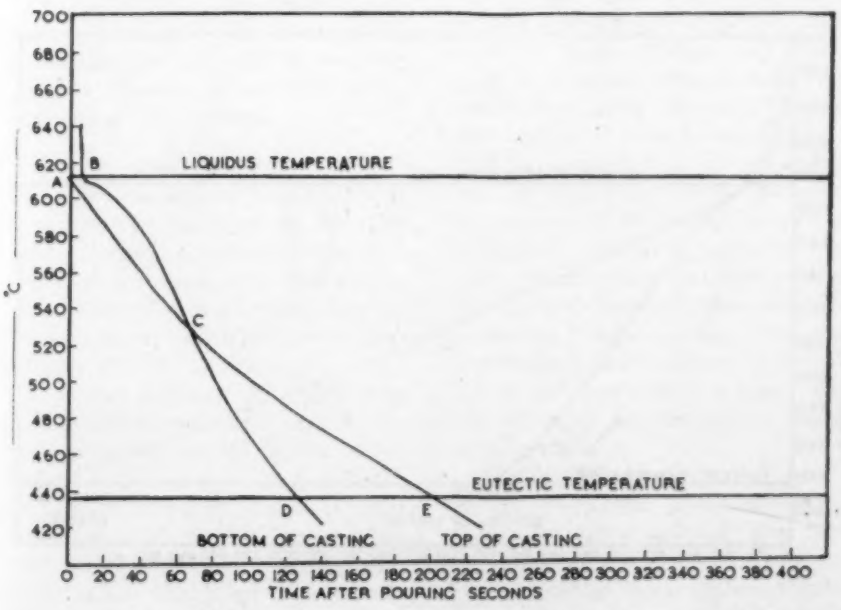
A high solidification factor means that during the major part of solidification the temperature gradients were favorable. The solidification factor is actually derived from the ratio of the amount of solidification that took place under a favorable temperature gradient to that taking place under an unfavorable gradient.

It will be seen that the loss in strength in the unfed castings depends essentially on the solidification factor, and that there is no real difference between aluminum and magnesium alloys in this respect. This point is illustrated in Fig. 12, which shows the relation between solidification factor and minimum relative strength of up-run bars.

This relation is independent of the alloy. However, there is one point on which a difference persists. In the unfed magnesium-alloy castings, the porosity takes the form of layers of porosity or of intense concentrations of porosity; whereas in the aluminum alloys no layers of porosity were detected by x-rays, although intense concentrations of porosity were found.

The most important conclusion from this work is that, owing to their low heat capacity, magnesium alloys solidify relatively fast in green sand molds, and that the temperature conditions tend to be less favorable to progressive feeding. Greater provision must therefore be made for feeding these alloys than for most other non-ferrous metals.

In other work of the Association on inverse segregation it has been shown that porosity in the last portions of a casting to solidify is associated with the draining away of the last portions of liquid. Experiments were made to determine whether there was a deficiency of the liquid which was last to solidify in porous parts of magnesium alloy castings.



Position of Test Bar (See Fig. 1C)

	A	*B*	*C*	*D*	*G*
Voids, per cent	0.6	0.6	0.1	0.1	—
$\frac{\text{UTS} \times 100}{\text{UTS}_{\text{DTD}}}$	42	65	61	79	50

Fig. 10—Temperature distribution during solidification and mechancial properties of test bars in 93/7 Mg-Al top-fed casting poured at 1364° F. (740° C.) into green sand mold. Feeder to casting ratio, 1:1.

VI. Miscellaneous Experiments on Layer and Annular Porosity

Analyses were carried out on samples drilled from porous patches in magnesium alloy castings, and these porous patches were found to be deficient in the last solidifying liquid. In binary aluminum - magnesium alloys the last remaining liquid is higher in aluminum than the remainder of the casting, and the analysis of the porous region shows deficiency in aluminum content. It follows, therefore, that some of the liquid has drained away during the last stages of solidification.

This was further proved by adding a small amount of copper to the alloy, since this copper is also associated with the last portions of the alloy to solidify. Again, a deficiency in copper was found in the porous regions. In this respect also, therefore, magnesium alloys behave similarly to other alloys.

Some castings were also made in magnesium-base alloys to which beryllium was added. Beryllium has the effect of increasing the grain size considerably until it approximates that of a coarse-grained aluminum casting with grain dimensions of the order of 3-4 mm., as compared with about 0.1 mm. for beryllium-free metal.

In these alloys a striking change was observed in the distribution of porosity, which tended to concentrate toward the center of the casting, the patches of porosity having roughly equal dimensions in three directions at right angles, with no layers of porosity such as were found in castings of the same form in a fine-grained material. It follows that the small grain size of the magnesium alloys is a factor contributing to the formation of layer porosity.

Chill-Cast Test Bars

Some experiments were also carried out with chill-cast bars. With cylindrical cast bars a ring of porosity is found at a distance from the chill face. It was found difficult to control this annular porosity in chill castings and to obtain reproducible results with castings solidified under apparently identical conditions.

To control the solidification conditions more precisely the molten

Table 2

CORRELATION BETWEEN PROPERTIES OF CASTINGS AND COOLING CONDITIONS IN THE MOLD

Casting Conditions					Properties of Castings									
					Porosity Voids, per cent				Relative Strength			$\frac{UTS \times 100}{UTS_{DTD}}$		
Alloy	Pouring Temperature, ° C.	Feeder/Casting Ratio	Mold Condition	Solidification Factor	A	B	C	D	A	B	C	D	G
93/7	740	1/1	Green	0.89	0.6	0.6	1.1	0.1	42	65	61	79	50
	740	1/1	Preheated*	9.4	0.7	0.4	0.4	0.0	73	86	79	98	76
Mg/Al	780	1.6/1	Green	2.8	0.6	0.3	0.8	0.1	70	74	64	77	62
	780	1.6/1	Preheated*	54.0	0.7	0.4	<0.1	0.0	77	75	77	89	84
95/5	770	1/1	Green	1.7	<0.1	0.1	0.3	0.1	109	75	51	102	50
	780	1/1	Preheated*	8.8	0.3	0.0	<0.1	0.1	100	81	84	98	73
Mg/Ni	800	1.6/1	Preheated*	15.5	0.4	0.0	0.0	0.1	100	88	86	97	80
93/7	770	0.5/1	Green	2.5	1.0	0.7	0.7	0.2	79	67	65	100	51
	770	1/1	Green	4.0	1.1	0.3	0.2	0.0	71	75	79	105	74
Al/Cu	780	1/1	80 gm. chill†	0.89	1.2	0.7	0.9	0.2	52	72	64	90	50
	780	1/1	120 gm. chill†	0.92	1.0	0.4	1.4	0.5	63	74	40	67	34

*Mold face heated to 100° C.
†Light chills of this total weight embedded along whole length of bar.

metal was held in cylindrical iron containers which were at the same temperature as the metal, and these were then lowered into baths of solder maintained at a constant temperature. It was hoped in this way to control the conditions of freezing exactly, and to be able to reproduce the annular type of porosity at will.

It was shown that fine-grained material tended to form annular porosity, but coarse-grained beryllium containing material showed central shrinkage. However, marked annular porosity was not always found in fine-grained material, and some other factor may operate which makes it difficult to invariably reproduce annular porosity in such material even with this close control of solidification conditions.

That annular and layer porosity are essentially similar and arise from the same cause was proved by a sand-cast bar poured unusually cold, which showed annular porosity in that part of the bar where the metal could freeze most rapidly, merging into the normal layer type further along the bar. In the intermediate region the porosity took the form of a series of small layers normal to the mold wall but arranged in an annulus.

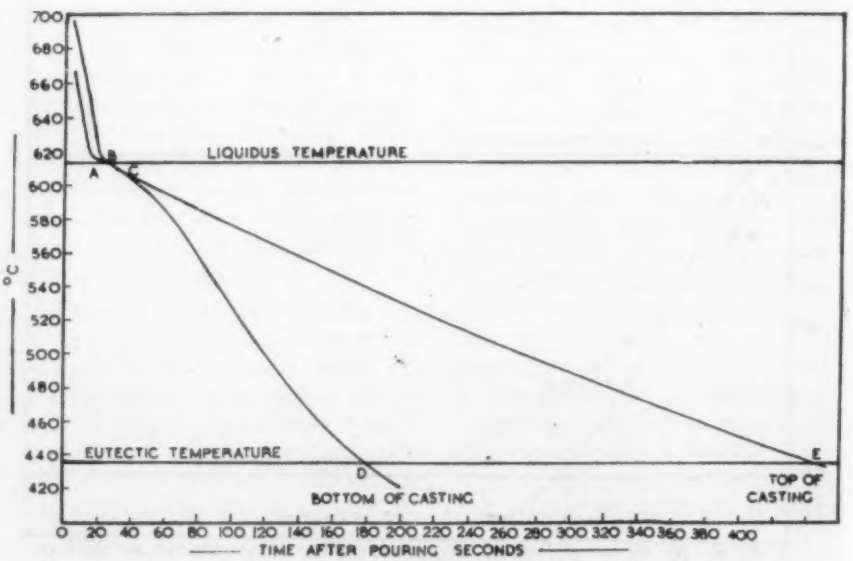
Experiments with magnesium-zinc (7 per cent) alloys showed that these alloys were moderately fine-grained and contained layers of porosity similar to those described previously except that the layers were deeper. In certain castings there were layers of eutectic similar in form to the layers of porosity shown in Fig. 14.

VII. Mechanism of Microporosity in Magnesium Alloys

Much of the mystery that has hitherto surrounded the occurrence of microporosity in magnesium alloys disappears with the findings (a) that under comparable conditions of solidification the strength of unfed castings in both magnesium and aluminum alloys is affected to the same extent, and (b) that it is more difficult to ensure correct solidification conditions in magnesium than in aluminum alloys.

It is proved that microporous areas in both magnesium and aluminum alloys are deficient in the last liquid to solidify, and that the porosity is therefore essentially due to shrinkage. Some differences between the two materials still remain for explanation, which must be somewhat speculative. These are as follows:

1. Under the same solidification conditions magnesium alloys show by density measurements less overall porosity than aluminum alloys.



POSITION OF TEST BAR (SEE FIG. 1C)	A	B	C	D	G
Voids, per cent	0.7	0.4	<0.1	0.0	—
$\frac{UTS \times 100}{UTS_{DTD}}$	77	75	77	89	84

Fig. 11—Temperature distribution during solidification and mechanical properties of test bars in 93/7 Mg-Al top-fed casting poured at 1436° F. (780° C.) into mold heated to approximately 212° F. (100° C.) Feeder to casting ratio, 1.6:1.

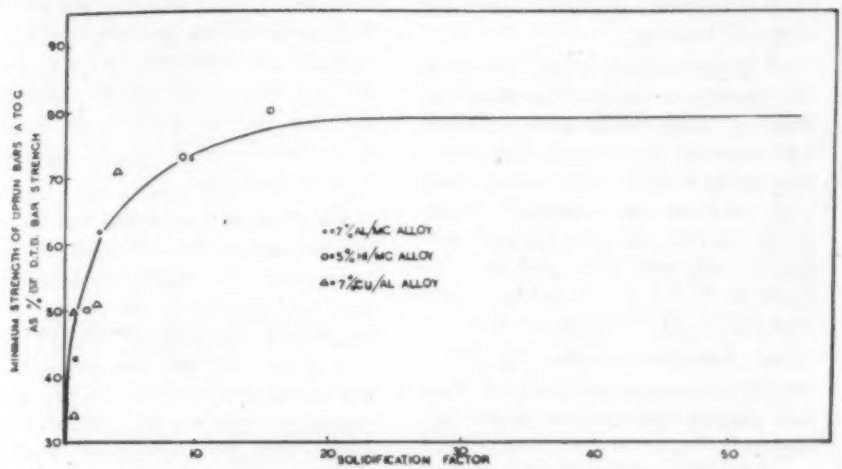


Fig. 12—Effect of solidification factor on minimum strength of up-run bars.

2. For a given amount of porosity, judged by density measurements, the strength of magnesium alloys is more seriously affected than that of aluminum alloys.

3. Gas in aluminum alloys may alter the form and/or distribution of porosity in an unfed casting, so that in some cases the strength is actually improved. In magnesium alloys gas does not affect the form of porosity, and no tendency to give a more uniform distribution of porosity or to improve the strength has been observed in this work.

4. Porosity in fine-grained magnesium alloy takes the characteristic layer form in sand casting and frequently appears as an annulus in cylindrical chill castings.

Dendrite Forms

These observations may be largely explained by the form of the dendrites in cast magnesium alloys. The dendrites in magnesium alloys form small rosettes with six main branches on one plane and with little if any growth at right angles.

Typical dendrites in magnesium alloys are shown in Fig. 13. In metals which solidify in the cubic system the dendrites tend to grow equally in three directions at right angles parallel to the faces of the cube. It is reasonable to assume that there is less likelihood of interlocking of the hexagonal dendrites as compared with cubic dendrites, since the former tend to grow in one plane and there is less chance of residual liquid being trapped and forming shrinkage or gas voids between the branches of the hexagonal dendrites.

Any shrinkage of liquid so trapped between the branches of the hexagonal dendrites is fed from one side or the other of the flat hexagonal plate. Hence, the overall soundness of magnesium alloys is greater, judged by density determinations, than for cubic metals.

Grain Size Effect

An added factor which is likely to contribute to the overall soundness of most cast magnesium alloys is their fine grain as compared with that of most aluminum alloys. A fine-grained material is more likely to feed with movement of the pasty mass of small crystals and liquid than is a coarse-grained material, where the large dendrites would tend to hinder mass movement.

If, as is suggested, the unsoundness in magnesium alloys will tend to concentrate at the outside of the hexagonal dendrites, whereas in cubic metals a large proportion may be trapped between the dendrite branches, it would follow that any unsoundness caused either by shrinkage or gas would have a more serious effect on the strength of hexagonal metals.

The occurrence of layers of porosity in magnesium alloys has been shown to be associated with the fine grain of properly melted metal. Coarse-grained metal does not show layers. It seems probable that these layers form at a late stage in freezing, while a pasty mass of small crystals and liquid is moving to compensate for shrinkage.

Apparently, local "faults" develop in this mass at right angles to its direction of movement and are pulled farthest apart at the center of a sand-cast bar where the movement is greatest. This mechanism is suggested by the observation on magnesium-zinc alloys, where it was found (Fig. 14) that the layers of porosity were in some cases associated with layers of low melting point liquid.

It seems likely that the faults developed in the moving mass of crystals may in some cases be healed by the influx of low melting point residual liquid, and the resulting pool acts as a local feeder at a later stage in freezing, the liquid draining away from this pool to feed freezing shrinkage in the adjoining metal. In other cases the faults may form at a later stage in freezing and may never then be healed.

In the case of chill castings the sound outer zone probably represents material which has solidified rapidly from the mold walls inward, and in the central, slightly unsound portion, mass feeding of small crystals and liquid has taken place. In this case the faults develop between the two zones. It should be remembered that the degree of porosity may be influenced by small variations in gas content below the limits detectable by the test used.

VIII. Magnesium Alloy Casting Technique

The most striking conclusion from the work described is that there is no essential difference between aluminum- and magnesium-base alloys in respect to loss of strength in unfed castings when the castings solidify at the same rate and under the same conditions of temperature distribution.

When a particular casting in a gas-free magnesium-base alloy shows a relatively greater loss of strength in unfed portions than would a gas-free aluminum alloy, this is because the magnesium alloy solidified much more rapidly than would the aluminum alloy, and the temperature conditions during solidification have therefore been less favorable.

The mechanism of microsporosity in magnesium-base alloys is essentially similar to that of any other non-ferrous metal, and is due to the draining away of the last portions of the metal to solidify from parts of the casting which cannot be properly fed. Owing to the more rapid rate of solidification of mag-

nesium alloys under similar conditions, they are more sensitive to poor temperature distribution in the mold.

It follows that the casting technique must be adjusted to ensure the best solidification conditions and proper feeding. In practice most magnesium alloy castings are bottom or middle run, and the metal is seldom poured directly into the mold through the cavity which is subsequently to act as a feeder. This is because of the danger of trapping oxide and flux in the casting if the metal flows in a turbulent, broken stream into the mold.

Such inclusions can seriously weaken the casting and make it highly susceptible to corrosion. At the same time, the necessity for bottom or middle running increases the difficulty of obtaining good temperature conditions in the mold, since, with top feeders, the metal which eventually reaches them is cooled as it runs through the mold and is cooler than the metal coming in at the bottom of the casting.

The experiments described in the following paragraphs illustrate this point and show the advantage of putting feeders at the bottom instead of at the top of the casting, since gravity is shown to play a minor part in feeding, at least in the last stages of freezing.

1. *Experimental Work.* Most of the work on various methods of running magnesium alloy castings was done on 7 per cent aluminum-magnesium alloy, but some tests were made on the proprietary alloys AZ31 (3 per cent Al, 1.5 per cent Zn, 0.3 per cent Mn) and A8 (8.5 per cent Al, 0.5 per cent Zn, 0.3 per cent Mn). The castings used were:

(a) Top-poured bars, Fig. 1B.

(b) "Conventional" bars, i.e., bottom poured with feeders at the top, Fig. 1C.

(c) Bottom-run bottom-fed bars, Fig. 1D.

2. *Results.* The advantages of a top-poured bar have been shown throughout the work of this research by the consistently high strength of the top-poured D.T.D. bars. These bars can be poured on the slope to avoid inclusions. The hot metal runs through the feeder cavity, heating it, so that the best temperature gradient is set up while the bar is solidifying. As the length of the bar increases it becomes more difficult to avoid inclusions and for the feeder at the top of the bar to accomplish its purpose.

Strengths approaching those of D.T.D. bars were found using a very slow rate of pour with the bar tilted. The use of a slow pouring speed introduces one difficulty; the metal in the pot loses heat rapidly, and by the time the bar is filled the metal in the feeder head may be too cold to feed properly.

The most striking result was found on comparing the strength of the "conventional" and "bottom-fed" bars. Averaging all the results, and taking the strength of the D.T.D. bars as 100 per cent, the strength of the bottom-fed bars was 84 per cent, compared with 62 per cent for the "conventional" bottom-run top-fed bars.

The cross-section of the downgate must, of course, be large enough to maintain pressure of the liquid metal on the bottom feeder until a coherent skin forms around the casting proper, and if this is done gravity plays little part in the final stages of solidification and feeding. The advantage of the bottom-fed bar lies in the fact that the incoming metal passes through the feeder cavity and heats it, and comparatively cold metal reaches the top of the bar.

The temperature gradient during solidification is, in this case, from bottom (feeder cavity) to top. The best results were found when the pouring speed was low enough to

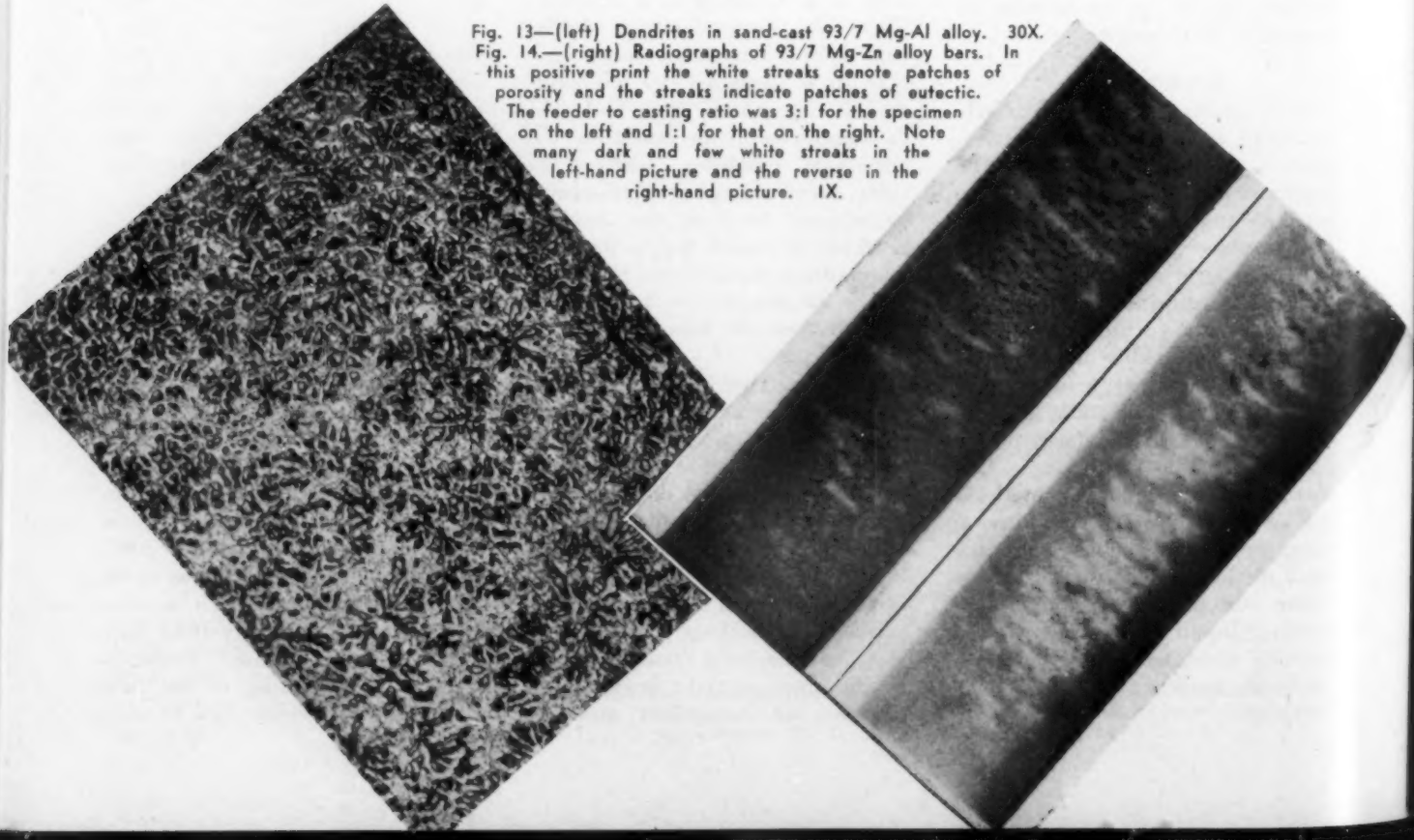


Fig. 13—(left) Dendrites in sand-cast 93/7 Mg-Al alloy. 30X.
Fig. 14.—(right) Radiographs of 93/7 Mg-Zn alloy bars. In this positive print the white streaks denote patches of porosity and the streaks indicate patches of eutectic. The feeder to casting ratio was 3:1 for the specimen on the left and 1:1 for that on the right. Note many dark and few white streaks in the left-hand picture and the reverse in the right-hand picture. 1X.

allow the metal to solidify just as the top of the bar was reached. With high pouring speeds the metal reaching the top of the bar was hotter and a less steep temperature gradient was set up. In heavy-section castings, in which the metal remains molten for a longer time, the possibility of convection currents causing the hotter metal to rise should also be kept in mind.

IX. Application to Foundry Technique

Although the results previously outlined are of considerable practical importance, they only show general principles. The castings made in magnesium alloys are much more complicated than the simple bars used in the laboratory, and it is seldom possible to run and feed a casting employing bottom runners and feeders only. In many cases it may be possible to get similar good conditions by middle running with the feeders at the ingates on the parting line.

There are also other ways of obtaining correct freezing conditions; for example, the side-running technique, in which the metal is admitted to the mold cavity by a side slit runner, or the use of a cross runner near the top of the mold, so that metal direct from the pot runs through it when the mold is nearly full and fills the top-feeder head with hot metal.

It is not possible to lay down hard and fast rules for good magnesium foundry practice since the casting technique depends so much on the particular casting, but the following points should be observed:

1. See that the metal is free from gas. This can best be done by using clean, dry metal that has not corroded in storage. If the metal has corroded, remove corrosion products by scratch brushing and preheat the metal out of contact with furnace gases, which usually contain much moisture. Test the melt by taking a small sample and allowing it to solidify under reduced pressure, as previously described. If the metal is gassy, allow it to solidify in the pot and remelt. The extra fuel involved is unimportant compared with the waste caused by porous castings.

2. Adjust the running and pouring conditions to ensure that the temperature conditions during solidification are such that the important parts of the casting solidify first and that the feeders are full of hot metal. The ideal to be aimed at is uniform progressive solidification in one direction from those parts of the castings remote from the risers to the risers.

Summary

Important factors to be remembered in casting magnesium alloys are:

(a) That magnesium alloys will lose heat more rapidly than any other commercial alloys when running through the mold.

(b) That feeder cavities can be preheated either by external heating (e.g., with a gas flame) or by allowing hot metal to pass through them.

(c) That feeder cavities need not necessarily be at the top of the casting since, provided the downgate is of sufficient cross-section, gravity is relatively unimportant in feeding, and hot metal will easily feed upward to parts of the casting where the metal is partly solid.

(d) That in the parts of the casting that matter most, the metal should remain as quiet as possible. Wherever a large volume of metal passes a particular point the sand becomes overheated. The metal at that point will remain molten longer and will feed nearby parts, and when it finally solidifies will contain shrinkage cracks or cavities. There is the added danger of gas pickup by reaction with the overheated sand.

(e) That dross and flux inclusions must be minimized by pouring as quietly as possible, and by the proper use of pouring basins and flux traps.

Use of the Cumulative Curve for
FOUNDRY SAND CONTROL

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IT IS BELIEVED that the present A.F.A. method of classifying molding sands does not give an adequate evaluation of their suitability as molding materials. Two sands, which are identical according to the A.F.A. classification, may show entirely different molding characteristics. Moreover, castings produced in one sand will be sound and of good quality, whereas castings produced in the other sand will contain porosity and have inferior surfaces.

This is why it is often impossible to obtain check results between foundries supposedly using the same grade of sand, and why inconsistent results are often obtained in a single foundry purchasing batch lots of sand from a single producer.

The problem, therefore, consisted of investigating methods of classifying sands and sediments which are used in other fields, to determine if they would help to overcome the deficiencies of the A.F.A. method; also, to modify and adapt the best of these methods to the grading of foundry sands and clays to the end that simple, accurate specifications could be developed for their purchase or designation as well as for their control.

• The purpose of this investigation was to develop a technique for adequate evaluation of particulate raw materials in foundry use—sands, clays, silica flour, and refractories. Additional work was undertaken at the Naval Research Laboratory subsequent to the presentation of the original paper at the 48th Annual Meeting of A.F.A., Buffalo, N. Y., April 26, 1944. The present complete report should serve to open further lines of investigation to improve foundry material control.

A satisfactory method should encourage development of knowledge in the silt-clay region, permit more accurate control of sand mixtures and raw materials, and permit the interchange of ideas on a more accurate and scientific basis.

General Considerations. The present A.F.A. method of determining sand fineness is based on the determination of clay by settling and decantation to remove the particles which settle at a rate of less than one in. per min., and separation of the grains which remain in a nest of sieves arranged so that the coarsest sieve is at the top of the stack.

The sieves must be of certain sizes and must meet rigid specifications. The fractions retained on the various sieves are then multiplied by factors, as shown in Table 1, to obtain the A.F.A. fineness number.

This test in its present form has several faults. At the fine end only one point is determined, which is the 20-micron separation. This is not a measurement of size but of the percentage of the material coarser or finer than 20 microns. Material finer than this size is called A.F.A. clay, but it could be nearly all fine silt composed of fine silica particles and actually contain very little active clay.

The directions for making this test are not entirely clear on what

Table 1

SAND FINENESS—WITHOUT SILT OR CLAY

Sieve	Retained, per cent	Multiplier	Product
6	0.10	3	0.30
12	1.20	5	6.00
20	5.60	10	56.00
30	6.28	20	125.60
40	16.72	30	501.60
50	17.76	40	701.40
70	9.68	50	484.00
100	4.30	70	301.00
140	2.00	100	200.00
200	1.44	140	201.60
270	1.04	200	208.00
	66.12		2785.50

A.F.A. Fineness No. $= \frac{2785.50}{66.12} = 42.12$

Table 2

SAND FINENESS—WITH SILT BUT WITHOUT CLAY

Sieve	Retained, per cent	Multiplier	Product
6	0.10	3	0.30
12	1.20	5	6.00
20	5.60	10	56.00
30	6.28	20	125.60
40	16.72	30	501.60
50	17.76	40	701.40
70	9.68	50	484.00
100	4.30	70	301.00
140	2.00	100	200.00
200	1.44	140	201.60
270	1.04	200	208.00
Silt (53-20 mu)	7.48	300	2244.00
	73.60		5029.50

A.F.A. Fineness No. $= \frac{5029.50}{73.60} = 68.36$

Table 3

SAND FINENESS—WITH SILT AND CLAY

Sieve	Retained, per cent	Multiplier	Product
6	0.10	3	0.30
12	1.20	5	6.00
20	5.60	10	56.00
30	6.28	20	125.60
40	16.72	30	501.60
50	17.76	40	701.40
70	9.68	50	484.00
100	4.30	70	301.00
140	2.00	100	200.00
200	1.44	140	201.60
270	1.04	200	208.00
Pan	33.88	300	10164.00
	100.00		12949.50

A.F.A. Fineness No. $= \frac{12949.50}{100.00} = 129.50$

is to be included in the silt-clay region. Some fineness analyses are made including the clay in the computations, while others are computed on the basis of grain material only. Some include silt but not clay. The former method naturally produces a much higher fineness number.

Tables 1 to 3, inclusive, show the computation of the A.F.A. grain fineness number in various ways. When the A.F.A. fineness number is found it gives a general idea of the size of the sand if one is familiar with the numbers, but they have little relation with any actual dimensions, and they show very little about the character of the sand.

The extensive bibliography of methods for particle size determination indicates the large amount of information in this field. Some of the more pertinent articles are discussed very briefly in the following to furnish a background for the techniques described later.

Krumbein[30] describes the history and progress of mechanical analysis from the decantation methods of ancient Greece to modern techniques. According to Krumbein, sieves were first used in 1704. In 1784 sedimentation was used for separation of a sediment into three grades, and in 1805 sieving and decantation were combined in a single technique. Elutriators were used in 1839. Stokes' law was formulated in 1851 and was applied to mechanical analysis in 1867.

The use of graphs to represent sediments was started in 1892, as well as the use of the centrifuge in mechanical analysis. Air analyzers were introduced in 1906 and the continuous sedimentation balance in 1912. Methods using a manometer were introduced in 1918, the pipette method in 1922 and the hydrometer in 1927. A bibliography of 186 articles is included as well as sketches of some of the early apparatus.

Dallavalle[16] has collected a large amount of material in his book, *Micromeritics*. Chapter 3 on "Shape and Size Distribution," Chapter 4 on "Methods of Particle Size Measurement," Chapter 5 on the "Theory of Sieving and Grading of Materials" and Chapter 6 on "Characteristics of Packings" are of particular interest to the foundryman. This is an excellent source of fundamental statistical information.

Sieve Systems

Investigators, in general, agree on measuring the clay sizes first, then removing the clay and analyzing the grain in a set of sieves. Several sets of sieves have been made which are satisfactory, the two most widely used in this country being the National Bureau of Standards and the Tyler systems.

In these series each sieve varies in a definite manner from the next in size; that is, the linear dimensions along one side of the square openings multiplied by a constant gives the linear dimensions of one side of the opening in the next larger sieve. Dallavalle[16] discusses various sieve series in Chapter 5 of his book.

Cumulative curves[59, 60] can be used effectively to represent sand size and distribution. A cumulative curve is simply a graph, usually having particle size as the abscissa and percentage of material retained as the ordinate.

Curves Defined

They are called cumulative curves because the sieves are usually placed in sets or stacks, and to find the percentage coarser than any particular sieve the amounts retained on the sieve and on all the coarser sieves must be added together. This distinguishes it from the size frequency curve in which only the amount retained on each sieve is plotted against size. Figure 1 shows a typical cumulative curve.

Analysis of the finer parts of sediments has been made in several ways. Trask[59, 60] used a centrifuge. Bouyoucos[5-12] and Casagrande[13, 14] used hydrometers. Robinson[51], Krauss[29] and Jennings[23] developed the pipette method independently. Krumbein[30, 31], the ASTM[1], and Jackson[22] have discussed the use of the pipette.

Methods Described

Oden[44] describes the use of manometers and specific gravity balances as well as the use of a continuous sedimentation balance which weighs the sediment as it accumulates on a submerged pan. Hellman and McKelvey[21] describe an interesting combination of pipette and hydrometer which utilizes the best features of each.

Thoreen[58] discusses the hydrometer method in considerable detail with a very clear explanation of the underlying principles. The hydrometer method is based on the fact that when a sample of material, such as a molding sand, is mixed with water, it increases the density of the resulting suspension.

When the suspension is allowed to stand, the particles settle out according to Stokes' law and the density of the suspension gradually approaches the density of the suspending medium. The amount of material in suspension at any time at the location of the hydrometer bulb is found from the hydrometer reading and the size is found by

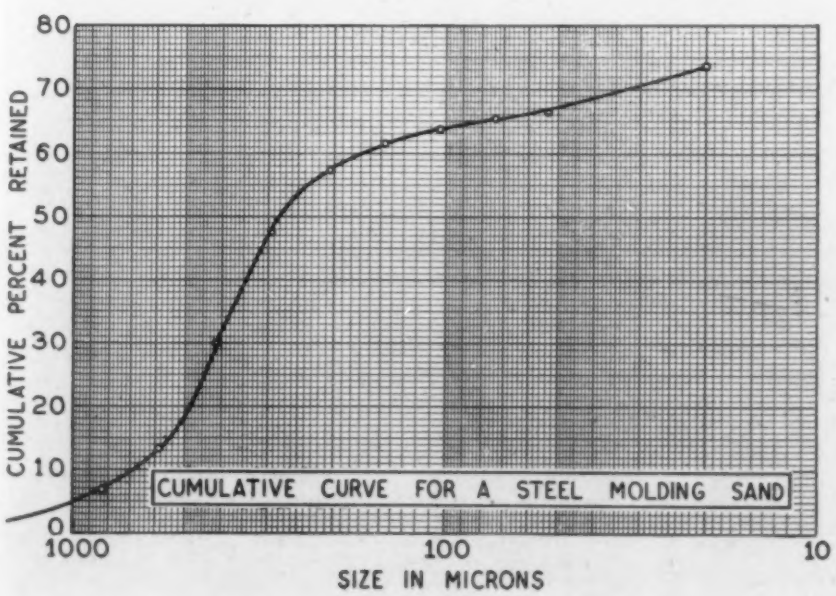


Fig. 1—A cumulative curve for a steel molding sand.

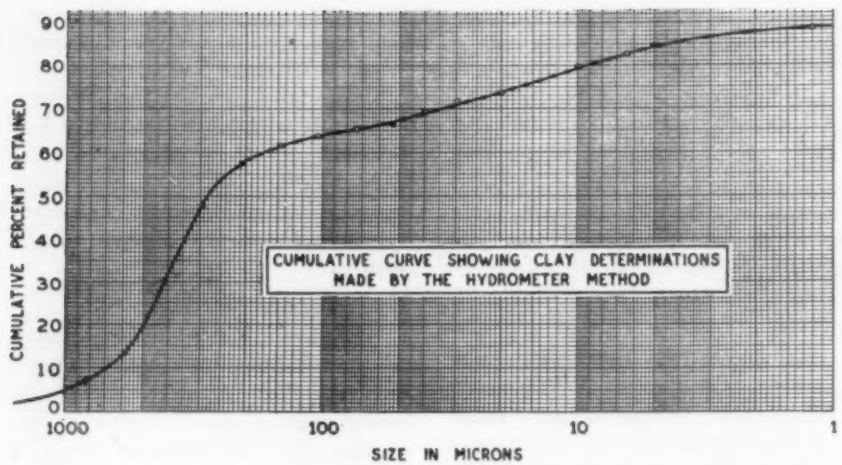


Fig. 2—Cumulative curve showing clay determinations made by the hydrometer method.

using the depth of the bulb and the settling time in the Stokes' law equation. The details are discussed later.

The hydrometer procedure used by the Department of Agriculture, Bureau of Public Roads, is described by Wintermeyer, Willis and Thoreen[64]. Willis, Robeson and Johnson[63] describe a graphical method of correcting the data, and Barber[4] developed a slide rule for making the corrections.

When many of these articles have been carefully read some salient facts appear:

a. The difficulties of the foundryman in the study of sand are no different from those of the oil man, the road builder or any other user of particulate materials sediments.

b. A great amount of work has been done by workers in allied fields on the determination of particle sizes and their representation.

c. Methods have been developed by them which are faster and produce more information than the method developed and standardized several years ago by the A.F.A.

d. It would be well to modify foundry sand laboratory methods for two reasons; first, to save time, and second, to get more information about our sands and thus lay the foundation for more accurate control and, therefore, better castings at lower cost.

Experimental Work. In order to evaluate the convenience and utility of methods cited in the foregoing and in the appendix, it was decided to try some of the more promising methods at the Naval Research Laboratory.

The first method to come under scrutiny was the pipette method described by Jackson[22]. He used a 50-gram sample of dried sand which is added to a solution made up of 475 ml. of distilled water and 25 ml. of a 3 per cent solution of NaOH.

This mixture is then dispersed with an electric stirrer mounted on a mason jar with baffles. The mixing period is 5 min. The sample is then transferred to a graduate and distilled water added to make one liter. The graduate is up-ended several times to place all the sand and clay in suspension, after which it is placed on a table and a stop watch started.

At some time after the beginning of the sedimentation period, which is determined by the size of separation wanted and the temperature of the suspension, a 25-ml. pipette is inserted into the liquid to a depth of 5 in. and a sample removed and placed in a weighed evaporating dish.

The sample is then evaporated to dryness and reweighed, the weight of dry clay plus NaOH is determined by difference and the weight of NaOH is subtracted, leaving the weight of clay in the pipette sample. Multiplying this amount by 80 gives the percentage of material finer than the size for which the test was made.

A nomographic chart (Fig. 14) from Jackson's work[22] is included in this report, which allows the settling time to be determined readily from the temperature and the size of separation desired. This method has been used successfully for several years at the Naval Research Laboratory, but is not entirely satisfactory.

It requires a sensitive analytical balance to weigh the evaporating dishes. The evaporating dishes are cooled in a desiccator after drying and, during weighing, begin to absorb moisture from the air, making weighing difficult. This can be overcome by using covered weighing dishes. The ground glass covers are closed when the sample is removed for weighing, and this eliminates the absorption of water and increases accuracy.

This method is time consuming and tedious if many determinations

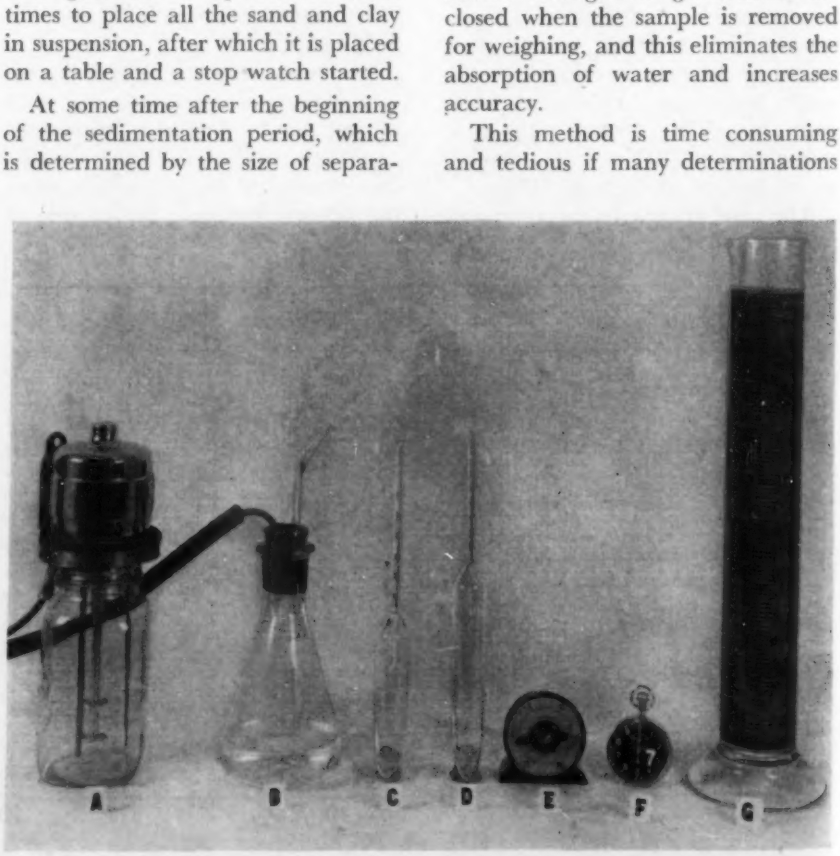


Fig. 3—Equipment used for sand particle size determination by the hydrometer method.

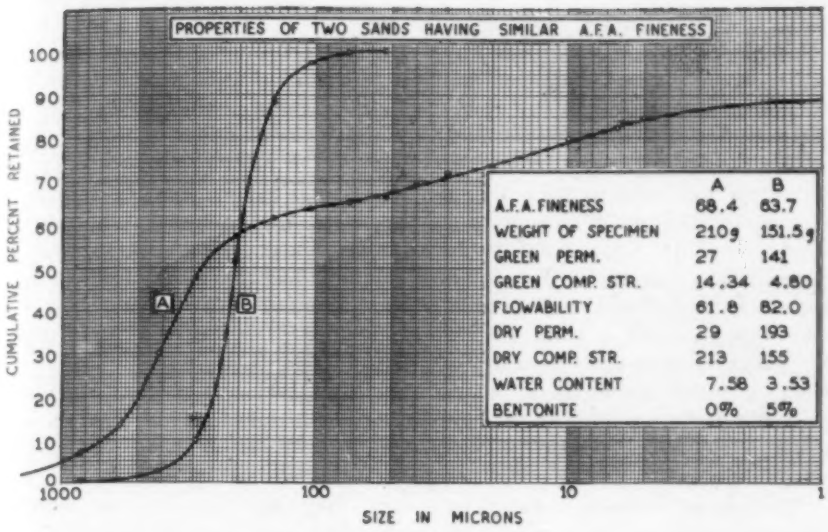


Fig. 4—Cumulative curves for two sands having similar fineness numbers but with physical property variations.

are required. It has one important advantage over the A.F.A. method in that determinations may be made at several sizes, thus providing data for cumulative curves in the clay region. This is important because it is due to the material in this region (less than 50 microns) that sand troubles often develop.

During the time the pipette method was in use, the practice of plotting sieve data as cumulative curves was adopted, and proved so much superior to the histograms previously used that they are now employed exclusively. A typical plot, sometimes called a "weight accumulation curve," is shown in Fig. 2.

Advantages of Method

Krumbein[33] has discussed the advantages and significance of this method. Trask[59] used it in his study of sediments in connection with the search for oil-bearing deposits. The median and quartile values used by Trask, as well as his method of determining distribution and skewness, are of considerable interest and are similar to methods described by Morey and Taylor[42] even though their methods were developed without knowledge of the previous work of Trask in the petroleum field.

Briefly, Trask's method is to plot his data on semi-log graph paper as a cumulative curve using "per cent retained" as ordinate and particle size as abscissa. The particle sizes at which the curve crosses the 25, 50 and 75 per cent retained lines are then read from the abscissa (usually in microns).

These points are called the first quartile, median size and third quartile. The median size is a very useful measure of particle size since 50 per cent by weight of the grains are larger and 50 per cent are smaller than this value. Morey and Taylor[42] called this "center grain size."

Trask, and Morey and Taylor, both used the ratio of the size of the first quartile to that at the third as a means of representing distribution, and Trask went a step further in taking the square root of this ratio which he calls coefficient of sorting:

$$So = \sqrt{\frac{Q_1}{Q_3}}$$

Q_1 and Q_3 being the grain size at the first and third quartiles, respectively. This is illustrated in Fig. 7.

Trask's formula for coefficient of skewness, Sk, is:

$$Sk = \frac{Q_1 \times Q_3}{M_2}$$

This represents the ratio of the slope in the second quartile interval to that in the third quartile interval. If Sk is 1, the sand has a normal distribution. If Sk is less than 1, the sand is skewed to the left and if greater than 1, the sand is skewed to the right. If a sand is skewed to the left it means that the mode, or maximum concentration of particles lies to the left of the median or to the coarse side and vice versa.

Trask shows that a skewness coefficient of 0.67 and 1.50 represent the same amount of divergence of the mode from the median but in opposite directions. In order to avoid any erroneous impression from this fact he uses the logarithm of the coefficient of skewness. The log of 0.67 is minus 0.13 and the log of 1.50 is plus 0.18.

Thus, instead of varying about unity the logarithms vary about zero negative values indicating skewness to the left and positive values to the right. Trask's data[59] (Table 6 pp 292-295), show the quartiles Q_1, M and Q_3, the coefficient of sorting So, the coefficient of skewness, Sk, and log skewness, $Log\ Sk$. He classified particle size of sediments as follows:

Larger than 1000 microns....gravel
From 50 to 1000 microns.....sand
From 5 to 50 microns.....silt
From 1 to 5 microns.....clay
Smaller than 1 micron
.....colloidal clay

This is a very logical nomenclature and might prove to be useful for foundry terminology.

From Trask's data it is possible

Table 4

Data Reported by Trask in Study of Sediments

Sample	*143B*	*174A*	*207A*	*270A*	*338*	*377*	*405*	*467*	*484*
Q_1	115	9.5	13	215	15	225	60	550	28
M	16	5.8	5.5	150	4.8	180	25	190	6.6
Q_3	5	1.6	1.1	62	1.3	80	3.7	48	1.8
So	4.80	2.44	3.44	1.86	3.30	1.70	4.04	3.38	3.94
Sk	2.25	0.61	0.47	0.59	0.85	0.56	0.36	0.73	1.12
Log Sk	0.35	—0.22	—0.32	—0.23	—0.07	—0.26	—0.45	—0.14	0.05
Gravel	4	0	0	11	Trace	0	Trace	11	0
Sand	28	2	10	68	3	81	29	63	15
Silt	43	48	46	6	45	10	40	9	42
Clay	25	35	23	7	34	7	26	15	29
Colloid	0	15	21	8	18	2	5	2	14

Table 5

STATISTICAL DATA ON STEEL FOUNDRY SANDS

Sample	*A*	*B*	*C*	*D*
Q_1	700	293	217	131
M	475	242	186	109
Q_3	338	210	152	90
So	1.44	1.18	1.195	1.206
Sk	1.05	1.05	0.953	0.993
Log Sk	0.021	0.021	—0.021	—0.007
Gravel	8	0	0	0
Sand	92	100	100	98
Silt	0	0	0	2
Clay	0	0	0	0
Colloid	0	0	0	0

to reconstruct cumulative curves to show the texture of his samples. Some of these are shown in Figs. 8 to 10. These curves also serve to illustrate the variety of sediments as they occur in nature. Trask's values are shown in Table 4.

Figure 11 shows some of the sands used as a base for steel molding sand mixtures. Statistical data on these sands are shown in Table 5. Comparing these curves with Figs. 8 to 10 shows at once the outstanding differences between natural deposits and washed and graded sands.

While the median size may be similar, the distribution, or sorting, has been changed considerably in the washing and sorting process, one sand deposit being sorted into four or more grades of sand in addition to the gravel and silt, most of which is discarded.

In examining these curves in detail we note that they cover most of the range of sand fineness which is commonly used in steel molding sand mixtures. The sizes range from 109 to 475 microns. The coefficients of sorting are all below 1.50, which indicates that the materials are extremely well sorted when compared with the normal sediments (Figs. 8 to 10) which have sorting coefficients as high as 4.80.

These skewness coefficients range from 1.05 to 0.95, which indicates relatively little skewness. Visual examination shows the curves to be symmetrical with no abnormalities.

Interesting in connection with the discussion of skewness are the sands shown in Fig. 12. They are steel molding sands which have been through a reclamation installation, the coarse sand being reclaimed sand which is normally rebonded and used over and the finer sand is the portion normally discarded as fines.

The similarity, illustrated in Fig. 13, of the fine sand to Albany sand was noted and, to determine if it would serve the same purpose, the material was bonded with a small amount of bentonite and dextrine and used to make a brass casting. It produced very good results and with a little development would probably make a good sand for light work in any metal except, possibly, magnesium.

The curves themselves show considerable skewness in opposite directions. This is the result of a fairly efficient "split" or separation in the hydraulic separating unit. The coarse fraction contains more than half of the grain material and comprises the "toe" of the curve before the separation was made. It is skewed slightly to the right.

The fine portion is skewed to the left and contains that material which formed the shoulder of the cumulative curve prior to separation. It is surprising to note that this material, believed to be worthless fines with a very large amount of inert clay, actually has only 21 per cent silt and less than 3 per cent clay. The remaining 76 per cent is good grain material.

After Jackson's method was used for some time to make a 20-micron determination, the need was felt for more points on the cumulative curve in the fine end, so the pipette method was used for other sizes as well, using the nomographic chart in Jackson's[22] paper and reproduced here as Fig. 14.

Determinations were usually made at 10, 5 and 2 microns. The results produced were good but the work

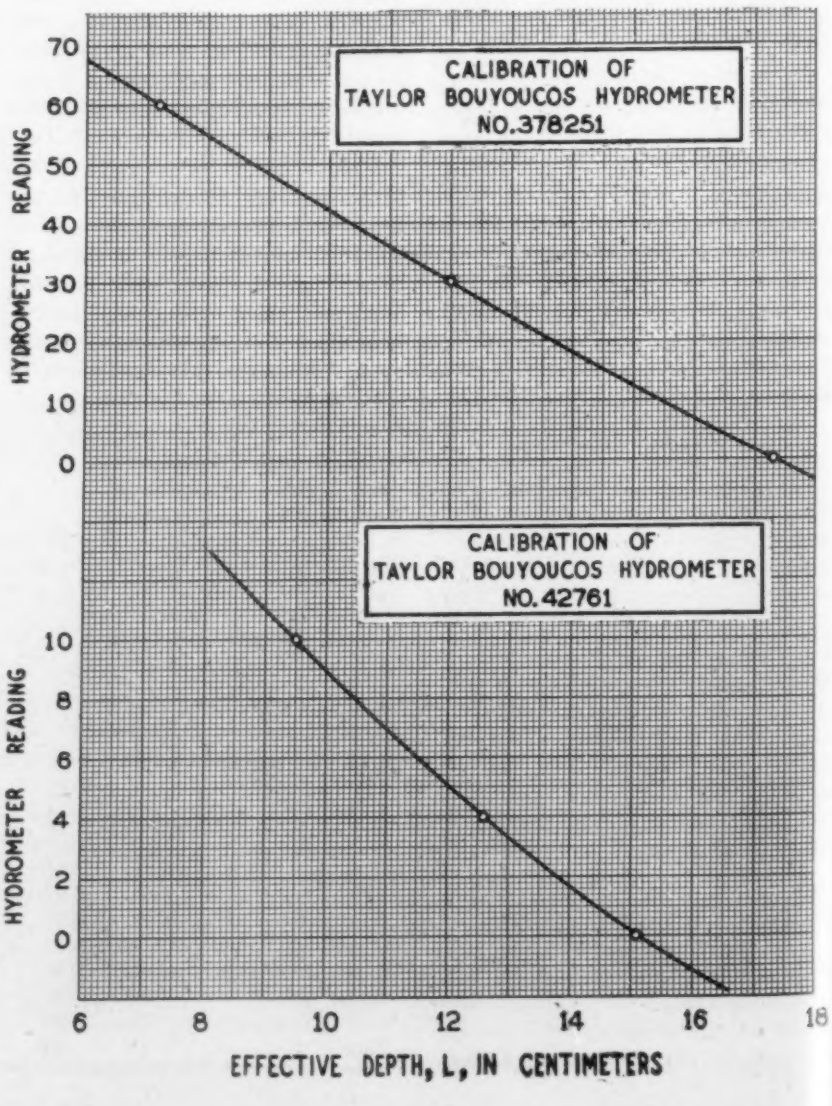


Fig. 5—Hydrometer calibration curves.

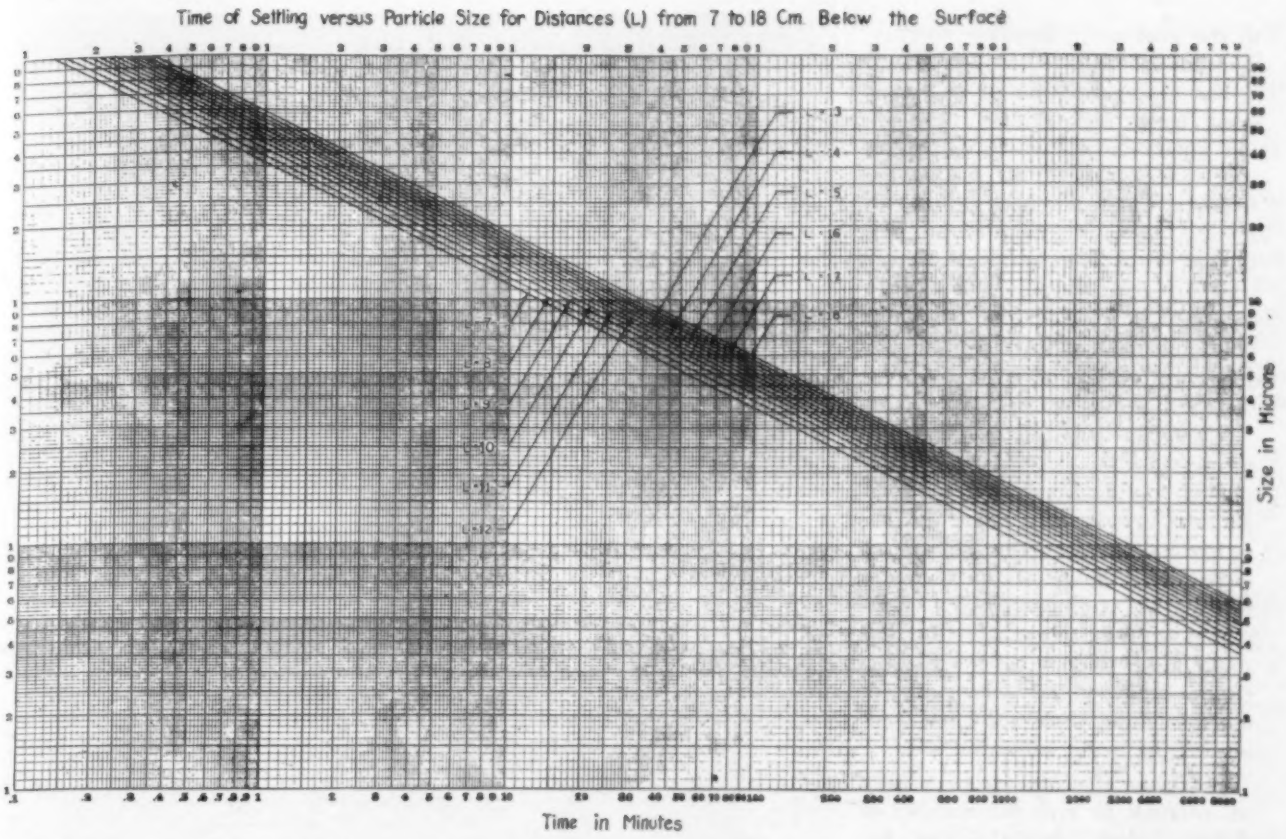


Fig. 6—Chart used to simplify calculations, showing relationship between settling time and particle size for various distances below surface.

was very tedious and time consuming if many points were to be determined. To simplify testing, several hydrometers were obtained and tried for the determination of clay.

It soon became apparent that a hydrometer for this purpose would have to be very sensitive. A Bouyoucos hydrometer was obtained and his method[5-12] was tried. His directions include determinations at 50, 5 and 2 microns. The agreement with the pipette method at 50 and 5 microns was good, but at 2 microns results did not check. It was then decided to investigate some of the more precise methods.

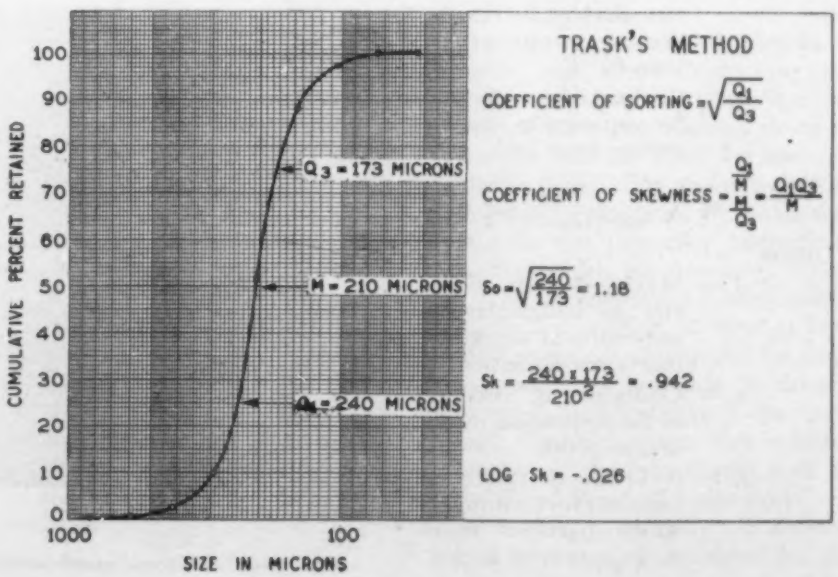
The method of the Bureau of Public Roads[64, 58, 4] was tried and found to give very rapid results. The equipment used in this method is shown in Fig. 3. Considerable care is needed in maintaining constant temperatures.

When the hydrometer is placed in the suspension it does not always float at the same height. As the particles settle toward the bottom, the remaining suspension becomes less dense and the hydrometer settles deeper. This causes a difference in the depth of settling which is used in the calculations. This consideration is discussed in detail later.

Briefly, the technique for using this method is as follows: 50 grams of dry sand is weighed and transferred to an electric stirrer. Five hundred ml. of distilled water and 5 ml. of normal sodium (meta) silicate solution is added. This is stirred for 5 min. and transferred to a one-liter cylindrical graduate.

To facilitate transfer, a bottle filled with distilled water is used having a connection to the compressed air line, a vent, and a jet. When the bottle is picked up, placing one finger over the vent causes air pressure to build up inside and a long thin stream of water to flow from the jet which quickly washes all material from the stirring cup

Fig. 7—Trask's method[59] for particle size distribution determination.


TRASK'S METHOD
COEFFICIENT OF SORTING = $\sqrt{\frac{Q_1}{Q_3}}$
COEFFICIENT OF SKEWNESS = $\frac{\frac{Q_1}{M}}{\frac{M}{Q_3}} = \frac{Q_1 Q_3}{M}$
Q_3 = 173 MICRONS
M = 210 MICRONS
Q_1 = 240 MICRONS
So = $\sqrt{\frac{240}{173}}$ = 1.18
Sk = $\frac{240 \times 173}{210^2}$ = .942
LOG Sk = -.026
CUMULATIVE PERCENT RETAINED
SIZE IN MICRONS

to the graduate. Distilled water is then added to make one liter.

The graduate is placed in a constant temperature tank (desirable but not essential) at 67° F. When it is at temperature, the graduate is removed and up-ended until all material is in suspension and well mixed. It is then returned to the constant temperature bath and a stop watch is started. Up to this point the method is very similar to Jackson's except that a different deflocculant is used.

When the cylinder has been returned to the tank and the timer started, the hydrometer is inserted and the first reading taken as soon as it comes to rest. The hydrometer is read at the top of the meniscus because the suspension is not transparent, but the error introduced is slight and is roughly balanced by the effect of the sodium silicate used as a deflocculant. Usually the first reading can be made within 30 sec.

Successive readings are then taken at intervals to give the number of determinations desired. The hydrometer readings and corresponding settling times are then used to determine percentages[58] and size in two separate steps by means of the following formulas:

$$P = \frac{(R \text{ plus } \Delta R)\ a \times 100}{W}$$

where

P = Percentage of originally dispersed sample remaining in suspension.

R = Hydrometer reading.

W = Weight of sample.

ΔR = Correction of hydrometer reading for variation in temperature from 67° F.

a = Correction coefficient for variation in specific gravity from 2.65.

and

$$d = \sqrt{\frac{30\ nL}{980\ (G - G_1)\ T}}$$

where

d = Maximum grain diameter in millimeters in suspension at any given time after dispersion.

n = Coefficient of viscosity of the suspending medium, in poises.

L = Average distance in centimeters through which particles settle in a given time period.

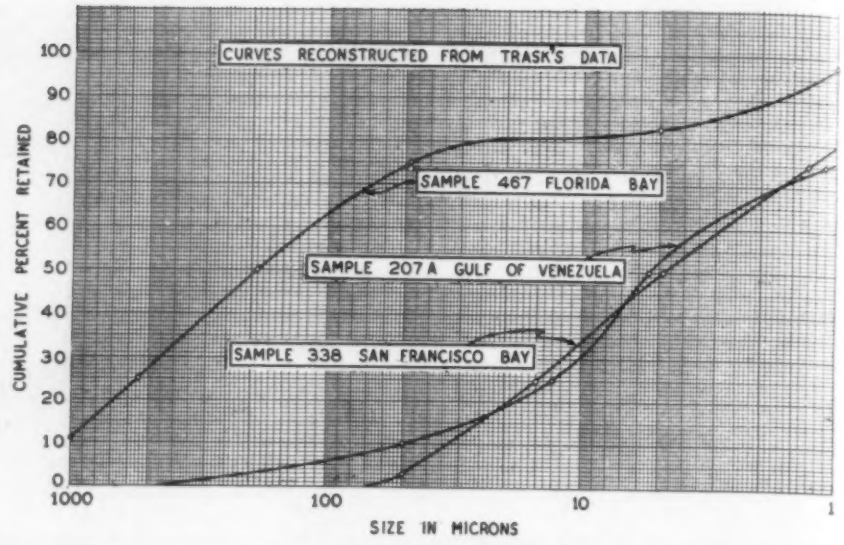


Fig. 8—Cumulative curves reconstructed from Trask's data[58] showing texture of samples (see Figs. 9 and 10).

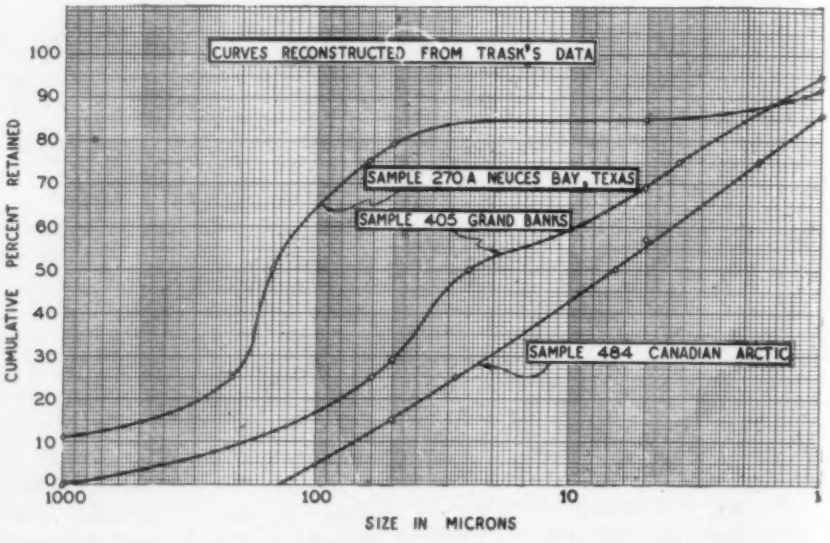


Fig. 9—Reconstructed cumulative curves of other samples from Trask's data (see Figs. 8, 10).

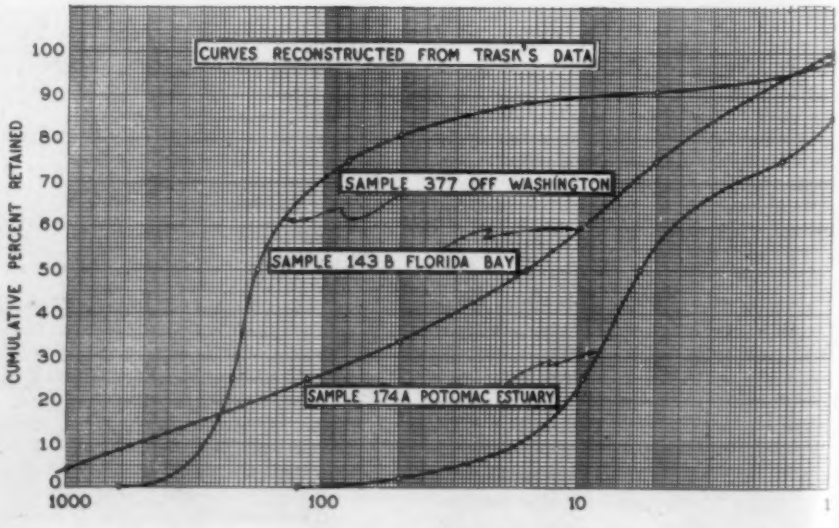


Fig. 10—Curves reconstructed from Trask's data (see Figs. 8 and 9).

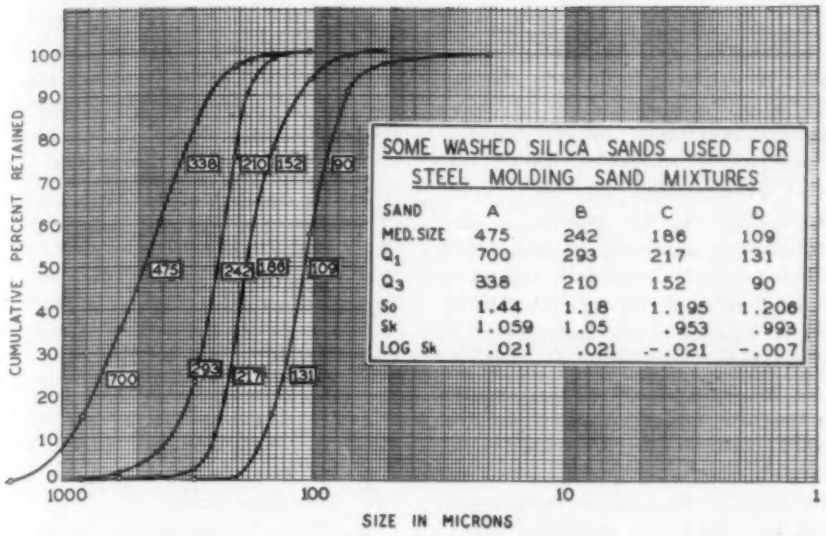

SOME WASHED SILICA SANDS USED FOR STEEL MOLDING SAND MIXTURES
SAND A B C D
MED. SIZE 475 242 186 109
Q1 700 293 217 131
Q3 338 210 152 90
So 1.44 1.18 1.195 1.206
Sk 1.059 1.05 .953 .993
LOG Sk .021 .021 -.021 -.007
CUMULATIVE PERCENT RETAINED
SIZE IN MICRONS
1000
100
10
1

Fig. 11—Distribution curves for washed and graded sands. Comparison with Figs. 8, 9 and 10 shows outstanding differences from natural deposits.

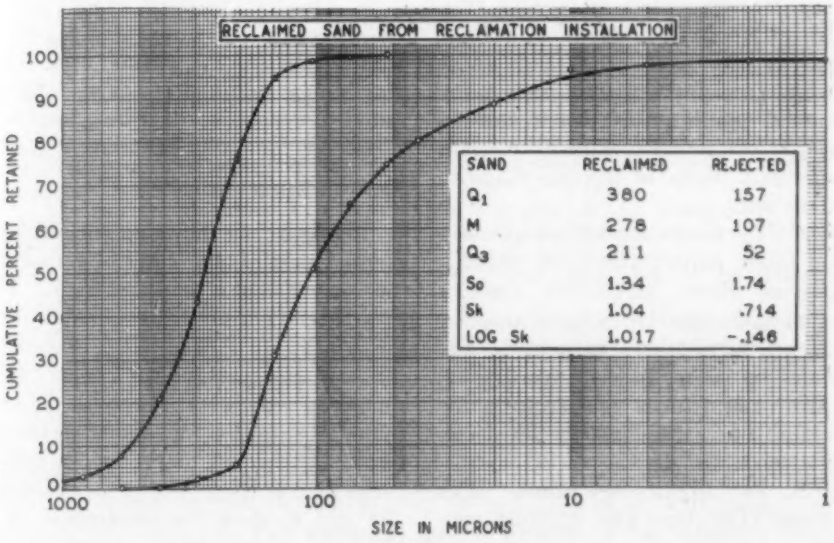


Fig. 12—Curves for steel molding sands from reclamation installation.

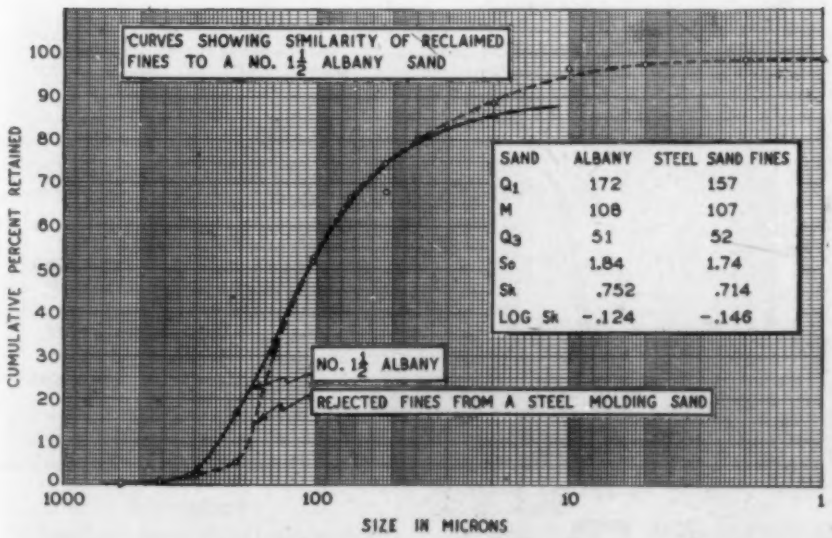


Fig. 13—Curves showing similarity between reclaimed fines (Fig. 12) and Albany sand.

T = Period of sedimentation in minutes.

G = Specific gravity of particles.

G_1 = Specific gravity of the suspending medium.

If a constant temperature tank at 67° F. is used ΔR may be omitted, and if the specific gravity is near 2.65, as in the case of most of the sands used for molding, "a" may be omitted. W is usually 50 so the first formula reduces to $P = 2R$, that is, the reading of the Bouyoucos hydrometer is multiplied by two.

In the second formula, if T is held at 67° F., n is 0.0102 poise, G is 2.65 and G_1 is 0.99841. The formula, therefore, reduces to:

$$d = \sqrt{\frac{30 \times 0.0102 \times L}{980\,(2.65 - 0.99841)\,T}} = \sqrt{\frac{0.000189\,L}{T}}$$

If d is desired in microns instead of millimeters,

$$d = \sqrt{\frac{198\,L}{T}}$$

L must be determined for each hydrometer. When employing a Bouyoucos hydrometer Thoreen[58] uses 0.42 of the immersed depth, and for the specific gravity type hydrometer a value equal to the depth from the free surface to the center of the submerged volume. It is believed that the latter method is better in either case.

Hydrometer Method Procedure

This distance may be found by filling a cylindrical graduate partly full of water, reading the volume, inserting the hydrometer to some particular hydrometer value, reading the volume on the graduate again, and then withdrawing the hydrometer until the water level on the graduate goes halfway down to the first reading. Hold the hydrometer at this position and measure the distance in cm. from the water surface to the particular hydrometer reading which was selected.

This distance is the L corresponding to that reading. If three or four such points are determined for each hydrometer a curve may be drawn, giving L as a function of the reading. Figure 5 shows this relation for two of the hydrometers used at the Naval Research Laboratory.

In order to simplify calculations a chart was made to show the re-

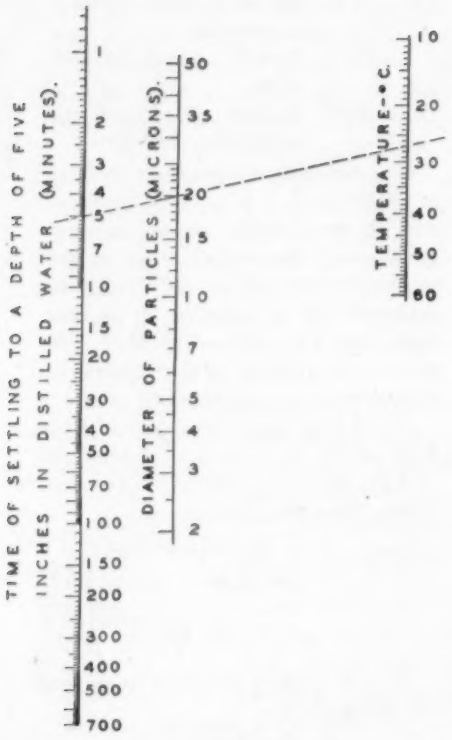


Fig. 14—Nomographic chart from Jackson's[22] method used to show temperatures, settling time, and particle size relationship.

lationship between T, L and d. It is shown as Fig. 6 and is derived from Stokes' law[58].

By using the two charts the hydrometer method becomes very simple, consisting of the following steps:

a. Reading the hydrometer and the corresponding settling time.

b. Determining L from the curve for the hydrometer used (Fig. 5).

c. Using the settling time and L, determining the size in microns from the chart (Fig. 6).

d. Determining the percentage of material finer than the size in microns by multiplying the hydrometer reading by two.

e. When several points have been determined, the clay is siphoned off, the sample dried, and sieved in the usual way. The sample can be siphoned to a depth of 12 in. after settling 4 min. This is repeated until the suspension is clear after 4 min. The water is decanted, the grain dried, and sieved in the usual way.

f. A cumulative curve of the sieve data is plotted using the hydrometer determinations in the silt-clay range to complete the curve. If cumulative percentages retained are used, each hydrometer percentage must be subtracted from 100 to put them on the same basis.

A hydrometer of the type used by Hellman and McKelvey[21] was made and tried. It has the advantage that the sample may be withdrawn from any desired depth. L, therefore, is predetermined instead of variable. The density of the sample in the pipette is approximately constant, so any error which might be caused by variation in the density of the suspension from top to bottom of the hydrometer is eliminated.

If temperature variations are corrected, this makes a simple tool for rapid routine clay determinations, but from the tests conducted to date the regular Bouyoucos hydrometer and the technique described previously gives more consistent results.

Since the cumulative curve method, in conjunction with hydrometer analysis, has been in use at the Naval Research Laboratory, several varied uses have been made of it which are indicative of the many further applications which can be found as familiarity with the method develops. Some of the uses made to date are:

a. To give essential information on sands, particularly in the silt-clay region where mysterious troubles sometimes develop. Such troubles as are attributable to particle size can be immediately determined. More often than not such is the case if fairly standard brands of raw materials are used.

b. For specifying sands, silica flours, clays, blast grit, grinding compounds, and similar raw materials. This application has been limited because of the inability of the supplier to provide complete analyses. However, many times it has been possible to describe requirements in terms of materials previously supplied and to indicate use of longer or shorter grinding times or different sieve sizes, to obtain useful results. Acceptance of this method as standard practice for particular materials would simplify specifications.

c. Various grades of silica flour which perform differently in practice, have been checked, reasons for their differences readily disclosed, and correction made.

d. Many commercial products marketed as highly specialized materials have given up their secrets when examined by this method.

e. One of the latest applications has been in the study of the powdered refractory materials used for investment casting. It has been possible to synthesize mixtures, thereby reducing cost and eliminating purchase of seemingly strategic materials.

f. Figure 15 shows an interesting application in the study of removal of fines from a molding sand. It was necessary to test a machine for its ability to remove such fines and it was not possible to collect the material which was removed. Silica flour (Curve B) was added to heap sand (Curve A) to produce a mixture high in fines (Curve C). Curves D and E show the progressive re-

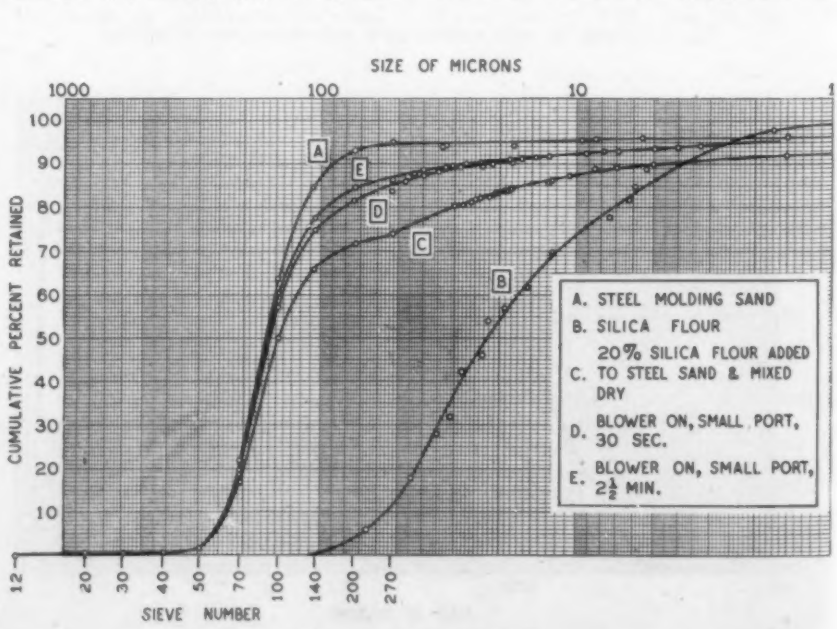

SIZE OF MICRONS
CUMULATIVE PERCENT RETAINED
SIEVE NUMBER
A. STEEL MOLDING SAND
B. SILICA FLOUR
C. 20% SILICA FLOUR ADDED TO STEEL SAND & MIXED DRY
D. BLOWER ON, SMALL PORT, 30 SEC.
E. BLOWER ON, SMALL PORT, 2½ MIN.

Fig. 15—Use of cumulative curves in test of machine for ability to remove molding sand fines.

moval of the fines with operating time. This is about the only technique which would accurately indicate the changing sand texture.

Conclusions

The use of cumulative curves at the Naval Research Laboratory for illustrating the particle size and distribution of foundry sands and clays has proved definitely superior to the A.F.A. grain fineness number ordinarily used for this purpose.

Sieve data for the coarser sand grains and the result of hydrometer analysis of the finer clay and silt are used in a single curve to give a comprehensive description of the material. This technique has proved particularly useful for specifying, controlling, and understanding foundry sands, clays, ladle refractories, silica flour and precision casting investments.

It is believed that the present standard A.F.A. grain fineness method does not give sufficient information about sands, and that it should be replaced by the methods described in this report. This would permit more accurate control of molding sand mixtures, simplify the selection and specification of molding sands and similar foundry raw materials, and permit the interchange of information on a more accurate and scientific basis.

It is recommended that consideration be given the possibility of developing specifications for foundry sands and other particulate materials on the basis of cumulative curves determined in the described manner, or in some equally accurate manner.

There is great need for the development of more precise information concerning clays as this is definitely the missing link in sand specification and control. While the hydrometer method gives a concise picture of particle size, more must be known about the nature of clays before their behavior in the foundry can be understood or improved materially.

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PROPERTIES AND CHARACTERISTICS OF COMMON *Magnesium Casting Alloys*

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BESIDES providing information on magnesium casting alloys, a particular purpose of this paper is to assist the founder, manufacturer, and design engineer in the problem of choosing the alloy most favorable for their particular application. In order to distinguish as much as possible between what is factual and what is subject to opinion, the paper is divided into two parts.

Part I presents pertinent technical data. In Part II the authors attempt to weigh these facts and to draw from them some practical working conclusions. Table 2 presents the nominal compositions of the alloys which will be covered, together with the designations commonly used in the United States and abroad. A brief historical sketch will serve to provide some perspective for the matters under discussion.

Prior to 1920, the casting alloy compositions used in Germany contained magnesium and zinc. Later, the AZG composition (Mg-6Al-3Zn-Mn) which corresponds to alloy "H"* was introduced and is still used[1]. For many years the German magnesium industry has also listed alloys of magnesium-aluminum-manganese-zinc, with aluminum in the range of 8-11 per cent and zinc up to a maximum of about 0.6 per cent.

The British magnesium industry makes use of these high aluminum-low zinc type alloys but has not looked with favor on the aluminum containing alloys with higher zinc content. The development in England has been summarized by Goddard[2], and discussions of British practice reviewed by Fox and Goddard[4,5].

In the United States at about 1920 the first casting alloys of importance were the magnesium-aluminum compositions, particularly Mg-8Al-Mn (0.0Zn). This casting alloy ("A") was used extensively until about 1937. The Mg-10Al-Mn alloy ("G") also came into considerable use about 1930.

These two casting alloys represented the entire usage in this country until about 1935. At this time the interest of the Armed Services of the United States in increased corrosion resistance of magnesium alloys in salt atmospheres led to the adoption of the high Zn containing alloy Mg-6Al-3Zn-Mn ("H").

Since "H" alloy did not offer the hardness, yield strength, pressure tightness and (in permanent mold applications) the castability comparable to the Mg-10Al-Mn alloy, there was a need for a new composition, with corrosion resistance comparable to"H" alloy, but having the previously mentioned properties.

This was provided about 1939 in the adoption of Mg-9Al-Mn-2Zn alloy ("C"), which was developed in this country** and apparently is not commercially used abroad. These two alloys have been used almost exclusively in the past few years for the production of magnesium castings in this country.

Due to the well-recognized tendency of "H" alloy to show microporosity and to the fact that "C" alloy, while much more sound, is still appreciably less sound than the original ternary Mg-Al-Mn or Mg-Al-Mn low Zn type alloys, there has been renewed interest in the utilization of the latter alloys for making pressure tight or highly stressed castings.

Table 1 has been prepared to illustrate relative practice in the United States, Great Britain, and Germany. Little is known concerning Japanese or Russian practice. The data in each case represent the approximate percentage use of each alloy in aircraft application. The German usage is deduced from examination of several captured German planes[1,16].

It is of interest that the German usage of AZG is to the extent of 25-30 per cent of their total casting requirements and always is in the as cast or as cast and annealed state. In contrast, the British do not use this alloy at all, while in the United States 75 per cent of the total production is in "H" alloy, although usually in the solution heat treated condition.

For engine parts subject to high stress, the Germans use the A9V (9Al-0.7Zn-Mn, solution heat treated) alloy, whereas U. S. practice is to use the heat treated and aged "C" or "H" alloy.

The fact that these different magnesium base casting compositions are being used for the same types of application in various countries

Relative usage in various countries from which information is available shows that the different magnesium-base alloys are being used for the same types of application. Within the range of composition of the alloys used and the present development of design and construction, the factors of design are of more importance than metallurgical factors. The majority of service failures are of fatigue origin, occurring because of inadequate design allowances for stress concentrations in the part.

*Denotes the Dow Chemical Co. alloy lettering system.

**This is a development of American Magnesium Corp.

and each of them successfully, brings up an important consideration which should be kept in mind in comparing these different alloys, namely, that metallurgical factors are far less important than design factors in determining the serviceability of a part, at least within the range of compositions under discussion and with the present state of development of light alloy casting design and construction.

The great majority of any cases of service failures have been of fatigue origin, and most of these fatigue failures have been the result of inadequate allowance in design for stress concentrations, brought about by the nature of the service function of the part, or more commonly such things as fillets, flanges, ribs, bolt holes and the like.

Failures are commonly noted to occur at these points in sound metal even though porosity may exist at other points in the part, often close to the point of failure. Similarly spot faces, undercuts, and marks and grooves due to poor machining cause many failures in castings.

The significance of the foregoing remarks is that in most cases serviceability is more likely to be determined by design and finish than by metallurgical factors, among which come soundness, alloy composition and condition. Thus, while the practical problem exists of choosing which alloy to use, its importance for serviceability should not be overemphasized.

Part I—Technical Data

The factual data are presented in three tables. Table 2 gives the properties as determined from standard test bars and various laboratory controlled experiments. Table 3 shows the properties obtained from bars cut from actual production castings. Rather than to test bars cut from castings it would be more conclusive to study field service comparisons of complete parts made from the various alloys. However, at the present time such comparisons are not available.

Table 4 lists "Foundry Characteristics." It will be recognized that some of these items, such as weldability, are necessarily qualitative. For the most part, the data in Table 4 came from observations of foundry behavior of casting alloys as handled on a commercial scale.

Table 1

RELATIVE MAGNESIUM PRACTICE

	United States	*Great Britain**	*Germany**
6Al-3Zn-Mn	H; AM-265	.....	AZG
Percentage of Production	75		30
AC (or ACS)	.....		Lightly Stressed Engine Castings
HT	Wheels		.....
HTA	Engine Parts		.....
9Al-2Zn-Mn	C; AM-260	.....	.....
Percentage of Production	24		
HTA	Engine Parts		
8Al-Mn (0.4 Zn)	A	A8	A8
Percentage of Production	.....	85	45
ACS		Miscellaneous small Parts	
HT		Wheels, Engine Parts	Wheels, Highly Stressed Engine Parts
9Al-Zn-Mn	R; AM-263	A9	A9
Percentage of Production	(Die Castings)	15	20
HT		Pressure Tight Applications	Engine Parts
10Al-Mn	G	A-10	A-10
Percentage of Production	1	.....	.....
HTA	Engine Parts (Perm. Mold)		
3Al-1Zn-Mn	.....	.....	AZ31
Percentage of Production			5
AC			Pressure Tight Applications

*Approximate proportional usage.

Composition and Properties

(Explanatory Notes to Table 2)

Density and Electrical Conductivity. The density and some of the conductivity data are from the 1944 "Dowmetal Data Book[6]." The remaining conductivity data are from other sources[10, 16].

Growth. Age hardenable magnesium alloys have the characteristic of occupying the least volume when in a single-phase condition. Conversely, they expand in direct proportion to the precipitation of a second phase and, hence, occupy maximum volume when fully precipitated. This phenomenon of increase in volume is known as growth.

The figures presented here represent the ultimate amount of unit dimensional growth that may occur on a given alloy and state due to further holding at elevated temperature (over 150° F.). The values given for the heat treated state, therefore, represent the maximum amount of growth that can be shown for that alloy composition.

The data given for "G" alloy are from Talbot and Norton[7]. The data were obtained for each condition by measuring the total increase in length of a 6-in. bar to the nearest 0.001 in. during an anneal at 350° F. The 350° F. anneal was continued until no further length changes occurred. This temperature was chosen as a standard for growth measurement since a maximum amount of aging in a relatively short time is obtained at that temperature.

Measurements at higher temperatures yield lower growth values since not as much precipitation occurs, while at lower temperatures essentially the same growth values are obtained, but very long periods of time may be required. Even magnesium alloys which have not been stabilized do not show any appreciable growth over a period of years at temperatures less than about 150° F.

In fabrication and use, growth

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may be of consequence if solution heat treated parts are used and are permitted to get hot for prolonged periods during machining, paint baking, or service. Extremely long parts that must be joined in assembly, or accurate instrument parts should be used in the de-growthed (aged or stabilized) states unless always used at temperatures less than 150° F.

Growth phenomena are not peculiar to magnesium alloys, and, as a matter of fact, age hardenable aluminum base and zinc base casting alloys show as much or more growth.

Corrosion. The first values given here are typical corrosion rates as determined by alternate immersion tests in 3 per cent NaCl solution. These values are somewhat a measure of corrosion in salt atmospheres, but they do not represent the relative corrosion rates of the various alloys in normal exterior exposure.

Figure 1 presents data indicating the effect of zinc on the corrosion behavior of commercial purity alloys. It will be observed that in general the corrosion rates of the German alloys, as shown by the crosses and circles, check fairly well with the American experience, as shown by the solid line.

The second two values, given for "H" and "A" alloys only, represent the corrosion behavior in two types of atmosphere. The first is a severe marine exposure, the second a severe industrial exposure. For the atmospheric tests the corrosion is expressed in terms of the percentage loss in tensile strength after exposure.

The effect of high zinc is of consequence only on commercial purity alloys[8]. Zinc exerts a specific effect to inhibit the bad corrosion effect of impurities such as iron, copper and nickel. If iron is held to a maximum of 0.002 per cent, nickel to 0.001 per cent and copper to 0.05 per cent, all of the compositions will show salt water corrosion rates of less than 0.2 mg/cm²/day, and, in fact, the low-zinc alloys will be slightly better.

Tensile Data. Properties are given at both room temperature and 300° F., the latter being selected as representative of the upper temperature range in which magnesium castings are normally used. Notched bar data were determined with a cylindrical notch having a radius and depth equal to one-tenth the root diameter.

This notch has a stress concentration factor of 2.4 in tension. Compression yield strengths are not given, since they are approximately the same as tensile yield strength data for magnesium alloy castings. The results are averages of from several hundred to several thousand test bars in each case.

Fatigue. These values were obtained by the R. R. Moore rotating beam method using sound, polished, separately cast test bars. Notched data in this case were obtained on similar bars machined to 0.300 in. and with a cylindrical notch having a radius and depth equal to one-tenth the root diameter. The stress concentration factor of this notch is 2.0 in bending.

In order to present a better picture of the fatigue strength, data are given at both 10^6 and 10^8 cycles. The values are the averages of a reasonably large number of tests. The figures are probably significant to plus or minus 1,000 psi. at fatigue strengths of 10,000 psi. or over, and to plus or minus 500 psi. at values under 10,000 psi. Here it will be noted that 275° F. was chosen for the elevated temperature data.

Plain Charpy Impact, Shear Strength, and Brinell Hardness. The shear strength and Brinell hardness are from the 1944 "Dowmetal Data Book[6]." The Charpy tests were run on bars conforming to standard dimensions, with the ex-

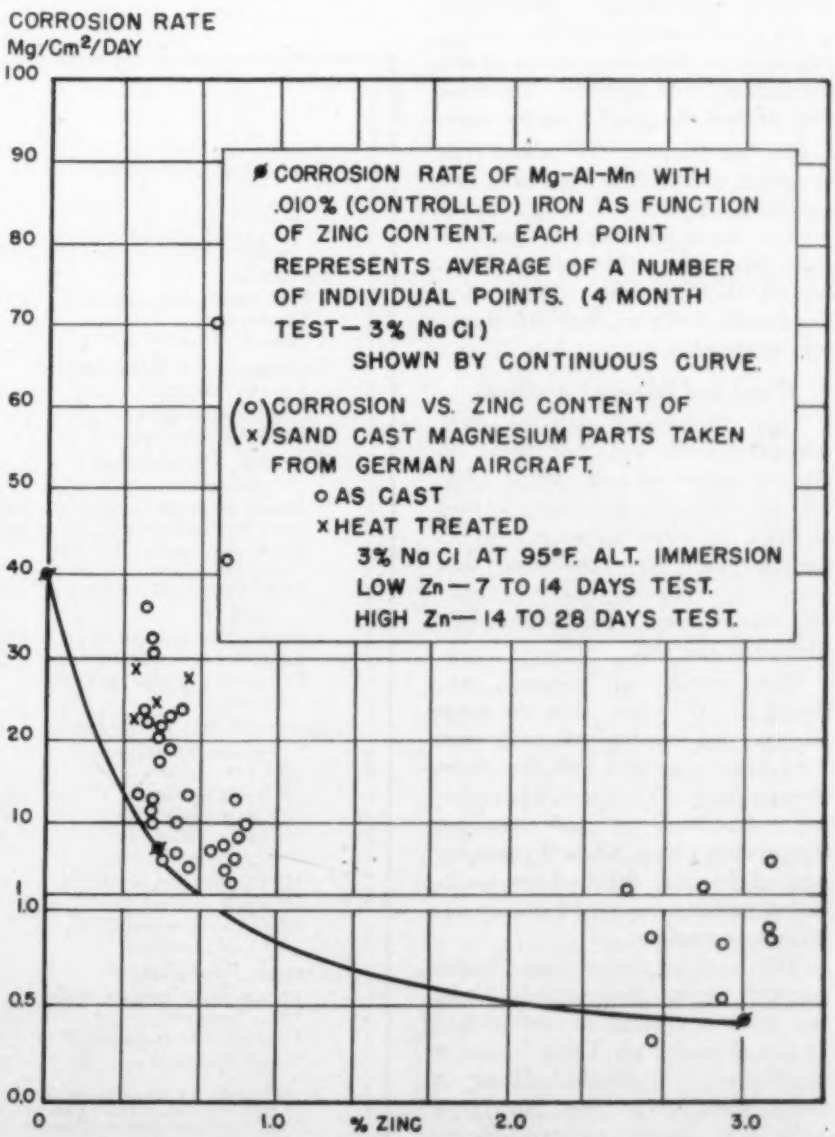

Fig. 1—Corrosion rate vs. zinc content in magnesium alloys. Comparison of German and American alloys.

ception of slightly rounded edges. These were present because the specimens were machined from 0.5 in. diameter cylinders. The values given are therefore slightly lower than would normally be obtained, but the relative relationships are not changed.

Properties from Production Castings
(Explanatory Notes to Table 3)

Although a large amount of information of a qualitative nature was available as a result of sporadic attempts to compare alloy compositions, this did not seem adequate for a semi-quantitative study of the relative behavior of these alloys for the production of commercial castings.

In view of this situation, a definite program was followed in the production foundry to evaluate three different types of alloy composition in the sand foundry and four different types of alloy composition in the permanent mold foundry. We shall first discuss the sand foundry tests.

For this purpose "H" alloy, representing the ductile, high zinc, low aluminum type; "C" alloy, representing the high strength, pressure tight type; and a third composition, Mg-9Al-0.2Mn-0.0Zn, representing the ductile, low zinc, high aluminum type, were chosen.

Metal and Pouring Conditions

Two commercial patterns were selected for the test; one being an aircraft engine oil pan casting (Fig. 2B) of large area and relatively thin sections, the other an aircraft wheel casting (Fig. 2C) containing thin and also relatively heavy sections and representing a part where ductility is important.

These castings are normally produced in "H" alloy. For the comparison, ten castings of each part were made in each of the three compositions. The melting, refining, superheating, and pouring temperatures were all held constant, and all foundry details were maintained under as nearly identical conditions as possible.

The castings were then radiographed quite thoroughly. These two types of castings are referred to as nos. 1 and 2 on Table 3, and a qualitative radiographic rating is there noted. The low zinc type alloy was better radiographically than the "C" alloy, which in turn was better than the "H" alloy. The castings were then tested as heat treated in the case of the wheel, and both as heat treated and as heat treated and aged in the case of the pan.

Test pieces were taken from each of the alloys and tested for corrosion in 3 per cent NaCl solution. These data are shown on Table 3. Three castings from each alloy and each part were cut in such a way as to get the largest possible number of test coupons from the casting. These were given the standard tensile tests, the average results of which are given in Table 3.

The values shown under the heading "Minimum" represent a value of each property which would be exceeded by 95 per cent of all the individual bars cut from the two different types of production castings. This is given as a measure of the dependability, or the probability of getting a certain level of properties in the actual castings.

Casting no. 3 (Fig. 2D) was handled in substantially the same manner as the preceding two castings, but with the inclusion of R. R. Moore fatigue tests on 20 bars cut from various locations.

Another type of casting was made in the experimental foundry (Fig. 2E), with the advantage that it could be cut to give a good survey of the effect of casting shape on tensile properties; that is to say, bars could be cut in such a way as to represent four different design situations which might be typical of those found in production castings as follows:

1. A heavily chilled area.
2. A section where two walls in-

Table

COMPOSITIONS AND PROPERTIES OF

ALLOY DESIGNATIONS	"C"					"H"				
Dow										
Other	*AM-260, ASTM No. 17*					*AM-265, ASTM No. 4, (MEL) AZG*				
Composition, per cent	*9.0 Al—0.13 Mn—2.0 Zn*					*6.0 Al—0.18 Mn—3.0 Zn*				
Condition	*AC*	*ACS*	*HT*	*HTS*	*HTA*	*AC*	*ACS*	*HT*	*HTS*	*HTA*
PHYSICAL										
Elec. Cond., mho-cm^{-1} × 10^{-4}	7.1		5.5		7.2	8.1		6.7		8.0
Density gms/cc	1.82					1.83				
Growth (Unit) × 10^{-4}	3.4	1.7	7.6	2.1	2.9	2.6	1.2	5.4	2.7	2.2
CORROSION OF BARE METAL										
3 per cent NaCl [5]	4		10		6	1.5		4		2
Coastal Atmosphere [6]						12		22.5		
Industrial Atmosphere [7]						3		5		1
TENSILE[4] PROPERTIES										
Room Temperature										
Tensile Strength (plain)	24.0	25.0	40.0	40.0	40.0	30.0	30.0	40.0	40.0	40.0
Yield Strength (plain)	14.0	14.0	16.0	20.0	23.0	14.0	14.0	14.0	17.0	19.0
Elongation (plain), per cent in 2 in.	2.0	2.0	10.0	3.0	2.0	6.0	5.0	12.0	7.0	5.0
Tensile Strength (notched)	22.5		34.5		37.0	27.0	27.5	37.5	37.5	35.5
300° F.										
Tensile Strength (plain)	26.0	24.0	31.0	28.0	28.0	27.0	26.0	29.0	27.0	24.0
Yield Strength (plain)	15.0	13.0	17.0	17.0	18.0	13.0	13.0	12.0	14.0	15.0
Elongation (plain), per cent in 2 in.	9.0	4.0	30.0	38.0	38.0	25.0	14.0	15.0	15.0	15.0
FATIGUE[4] (R. R. Moore)										
Room Temperature										
10^6 Cycle (plain)	16	16	18	17	18	12	18	17	18	17
10^8 Cycle (plain)	13	13	16	13	15	10	12	16	15	15
10^6 Cycle (notched)	10		14	12	11	10	10	12	12	11
10^8 Cycle (notched)	8		12	9	9	7	9	8	9	9
275° F.										
10^6 Cycle (plain)	15	9		12	13		11		11	12
10^8 Cycle (plain)	9	8		9	10		8		9	7
10^6 Cycle (notched)	8	6		8	9		7		7	8
10^8 Cycle (notched)	5	4		4	6		6		5	5
OTHER PROPERTIES[4]										
Plain Charpy Impact, ft. lb.	2.3		16.5		4.4	4.7		34		8
Shear Strength	18.0		20.0		21.0	18.0		19.0		20.0
Ultimate Comp. Strength	55.0		60.0		70.0	45.0		46.0		50.0
Brinell Hardness	65		63	75	84	50		55	59	73

[4] Primarily the data refer to sand and permanent mold castings.
[5] MEL A-9 may contain 0.6 per cent max. Zn.
[6] MEL A-8 may contain 0.4 per cent max. Zn.
[7] Maximum.

ersect to form a cross.

3. A gate area.

4. A relatively thin area which would be difficult to feed.

Test Coupons

This casting also permitted the cutting of test coupons which would be tested in fatigue. This casting is designated as no. 4, and the average tensile and fatigue properties are shown in Table 3. In the case of the fatigue data (R. R. Moore), the values were obtained on polished bars cut from three selected positions as follows:

Sound position was from a heavily chilled area.

Unsound position was from a porous area adjacent to the gate.

Intersecting Wall position was selected in moderately sound metal, but so chosen that the bar was machined with the reduced section of the fatigue bar including the metal originally at the point of casting wall intersection.

For the evaluation of alloy compositions in the permanent mold foundry three patterns (Fig. 2F) were selected. In each of these, four compositions, "C", "H", "R", and "G" alloys were tested. Average tensile data on test bars cut from these castings (casting nos. 5, 6, and 7) are as shown in Table 3.

Foundry Characteristics

(Explanatory Notes to Table 4)

Freezing Range. This represents the range encountered in production castings between the liquidus temperature and the temperature at which the final liquid solidifies. Two figures are given for each case. The first one is the difference between the liquidus and the solidus temperature for the alloy[10]. This is the range to be expected under equilibrium conditions and represents a minimum for any freezing condition.

The second figure is obtained by first determining the melting point of the lowest melting constituent in a sand casting, considering this temperature as a "non-equilibrium solidus," and then expressing the freezing range as the difference between this temperature and the liquidus. This latter range is the one most closely approached in all practical casting operations.

Fluidity. These are data obtained with the standard A.F.A. fluidity spiral of trapezoidal cross section when cast at 1400° F. The reproducibility is about ± 1 in.

Castability. This is the general ability to fill a mold and give adequate reproduction of shape and detail without excessive casting defects. The data given were based on the production castings listed in Table 3.

Pattern Shrinkage. Pattern shrinkage is defined as the linear change in inches per foot as the casting cools from the molten state at the pouring temperature to room temperature. It is the same for all compositions and equal to about 5/32 in. per ft. This figure can vary within rather wide limits, depending upon restraint conditions present.

Melting Loss. These data were obtained on a continuous melting, alloying, and casting cycle, wherein about 50,000 lb. of each alloy were accurately weighed in and out. The melting loss represents one cycle of melting, alloying, and pouring. The data were obtained on "C", "H", and "G" alloys, and the values given for "R" and "A" alloys were estimated by consideration of their similarity in composition and known behavior.

It should be appreciated that these are indications of the relative melting losses under one particular set of melting conditions, and the absolute values may be considerably lower under more favorable conditions.

Porosity Tendency. Here the alloys are rated on the basis of the relative amounts of radiographic porosity in a standard porosity test panel (Fig. 2A). Zero (0) is least

2

MAGNESIUM ALLOYS—CASTINGS*

"R" AM-263, ASTM No.13, MEL A-9[1] 9.0 Al—0.15 Mn—0.7 Zn					"G" AM-240, ASTM No. 2 10.0 Al—0.13 Mn—0.3 Zn			"A" MEL A-8[1] 8.0 Al—0.3 Mn—0.3 Zn[1]		
AC	ACS	HT	HTS	HTA	AC	HT	HTA	AC	HT	HTA
7.1		6.0		7.6	6.7	5.5	7.2	7.6	6.7	7.2
1.81					1.81			1.80		
4.0	2.1	7.7	2.6	3.6		21.0	10.0			
17		24			20	50	30	17	25	
								22	45	
								2	5	7
25.0	25.0	40.0	40.0	40.0	24.0	39.0	39.0	30.0	39.0	39.0
14.0	14.0	14.0	18.0	21.0	16.0	14.0	20.0	12.0	11.0	16.0
4.0	3.0	12.0	4.5	4.5	1.0	10.0	2.0	5.0	13.0	7.0
24.0	22.0	35.5	36.5	36.0						
	25.0		27.0	27.0			28.0			27.0
	13.0		15.0	14.0			14.0			10.0
	7.0		30.0	40.0			30.0			26.0
	16	18	15	15	16	18	16			
	12	15	12	10	12	14	11			
	10	12	10	10	10	12	11			
	6	9	7	7	7	8	9			
	11		13	11						
	9		10	7						
	7		7	6						
	5		5	4						
2.6		32.4		4.2	2.6	17.2	4.6	3.8	37.2	14.7
					17.0	19.0	21.0			
					48.0	50.0	54.0			
52	59	53	64	66	54	52	69	52	50	56

[1] All stress values in units of 1,000 psi.
[2] 14-day test by alternate immersion (95° F.). Expressed as loss in weight—mg/cm²/day.
[4] Exposed 4 yr. in racks 80 ft. from ocean surf. Expressed as per cent loss in tensile strength.
[7] Exposed 4 yr. in racks at Midland, Mich. Expressed as per cent loss in tensile strength.

porosity. This porosity panel has been described by Busk, Marande, and Newhams[11], and is a flat, rectangular panel attached to a tension test bar mold.

It is so gated that it will show a small amount of porosity even in the soundest alloy compositions. It will be appreciated that this is a drastic test, and alloys that would show unsoundness on this panel might show a better degree of soundness in actual production castings.

Pressure Tightness. This again is a qualitative rating wherein one (1) is best. The tests were made on a standard hollow cylindrical casting gated and poured under identical conditions for each alloy (Fig. 2A). All of the alloys can be made pressure tight, but the figure given is a qualitative indication of the relative ease with which pressure tightness is accomplished.

Hot Cracking Tendency. Hot cracking is not a problem unless excessive restraint is present, such as may be the case in the permanent mold foundry or with large steel inserts in the sand foundry.

Cold Brittleness. This is a qualitative rating representing the likelihood of breakage in handling and straightening a cold casting. One (1) is best. None of the alloys is especially bad as compared to other structural metals.

Grain Size. The magnesium alloys represented in this table are all amenable to grain refinement by the commonly known refining and superheating treatments[12]. When such treatments are properly given, the grain sizes will all be about equally fine and of the order of 0.004-0.006 in. average grain diameter.

Germination Tendency. This is a semi-quantitative rating of the relative tendency of the alloys to grow excessively large grains during solu-

Table 3

PROPERTIES OF BARS CUT FROM SEVEN DIFFERENT PRODUCTION CASTINGS

Casting No.	Type Casting	Type Average	Test [1]	Alloy "C" HT	"C" HTA	"H" HT	"H" HTA	"R" HT	"R" HTA	"G" HT	"G" HTA	"A" HT	"A" HTA
1	Sand	Arithmetic mean	T.S.	41	41	37	36					36	38
			Y.S.	19	23	14	19					14	20
			Per cent E.	7.2	2.5	10.3	4.2					9.7	3.4
		Minimum [2]	T.S.		29		24						31
			Y.S.		20		12						17
			Per cent E.		0.2		0.5						0.5
		Arithmetic mean	3 Per cent NaCl [3]		3.73		0.75						8.34
			Radiographic Rating		2		3						1
2	Sand	Arithmetic mean	T.S.	32		30						30	
			Y.S.	19		13						14	
			Per cent E.	2.5		5.9						6.3	
		Minimum [2]	T.S.	20		20						18	
			Y.S.	13		11						11	
			Per cent E.	0.5		1.5						1.5	
		Arithmetic mean	3 Per cent NaCl	12.9		6.4						32.0	
			Radiographic Rating		2		3						1
3	Sand	Arithmetic mean	T.S.			31.4						32.4	
			Y.S.			14.1						13.5	
			Per cent E.			6.5						10.2	
	Sound Area	10^8 Cycles	Fatigue			10.0						11.0	
	Unsound Area	10^8 Cycles	Fatigue			7.5						11.0 [5]	
4	Sand	Arithmetic mean	T.S.	30.6	35.4	31.5	33.6	34.8	33.5	33.4	35.3	33.8	35.9
			Y.S.	14.7	21.2	12.3	17.6	11.7	15.4	15.1	22.0	12.9	18.7
			Per cent E.	5.9	2.0	7.9	3.3	10.2	5.0	6.8	1.3	8.6	3.7
	Sound Area	10^8 Cycles	Fatigue	16.5	15.0	15.1	12.0	15.5	12.1	15.0	12.0	11.2	10.5
	Intersecting Wall	10^8 Cycles	Fatigue	13.0	10.5	10.8	11.1	15.0	9.8	11.5	11.0	11.5	9.0
	Unsound Area	10^8 Cycles	Fatigue	9.0	8.0	9.8	10.0	11.5	10.0	10.8	10.9	11.5	10.0
5	Permanent Mold	Arithmetic mean	T.S.	32	32	27	29	27	27	30	26		
			Y.S.	16	22	13	16	13	15	15	22		
			Per cent E.	5.4	1.3	4.2	2.7	6.0	3.6	7.0	2.3		
6	Permanent Mold	Arithmetic mean	T.S.	30	29			27	27	23	28		
			Y.S.	14	20			14	21	15	22		
			Per cent E.	1.2	1.8			3.0	1.8	1.4	1.3		
7	Permanent Mold	Arithmetic mean	T.S.	28	28	30	30	31	28	27	30		
			Y.S.	18	22	15	19	16	20	14	18		
			Per cent E.	1.7	0.6	6.3	3.5	6.0	3.7	5.7	3.2		

[1] All stress figures are in units of 1,000 psi.
[2] The property value which 95 per cent of all specimens will exceed.
[3] Corrosion rate in mg/cm²/day during alternate immersion.
[4] These tests were purposely made with Mg + 9 per cent Al + Mn which is at the top limit of "A" alloy.
[5] Bars from this area when poured in "A" alloy were sound, and therefore had the same fatigue limit as the bars from the "sound" area.

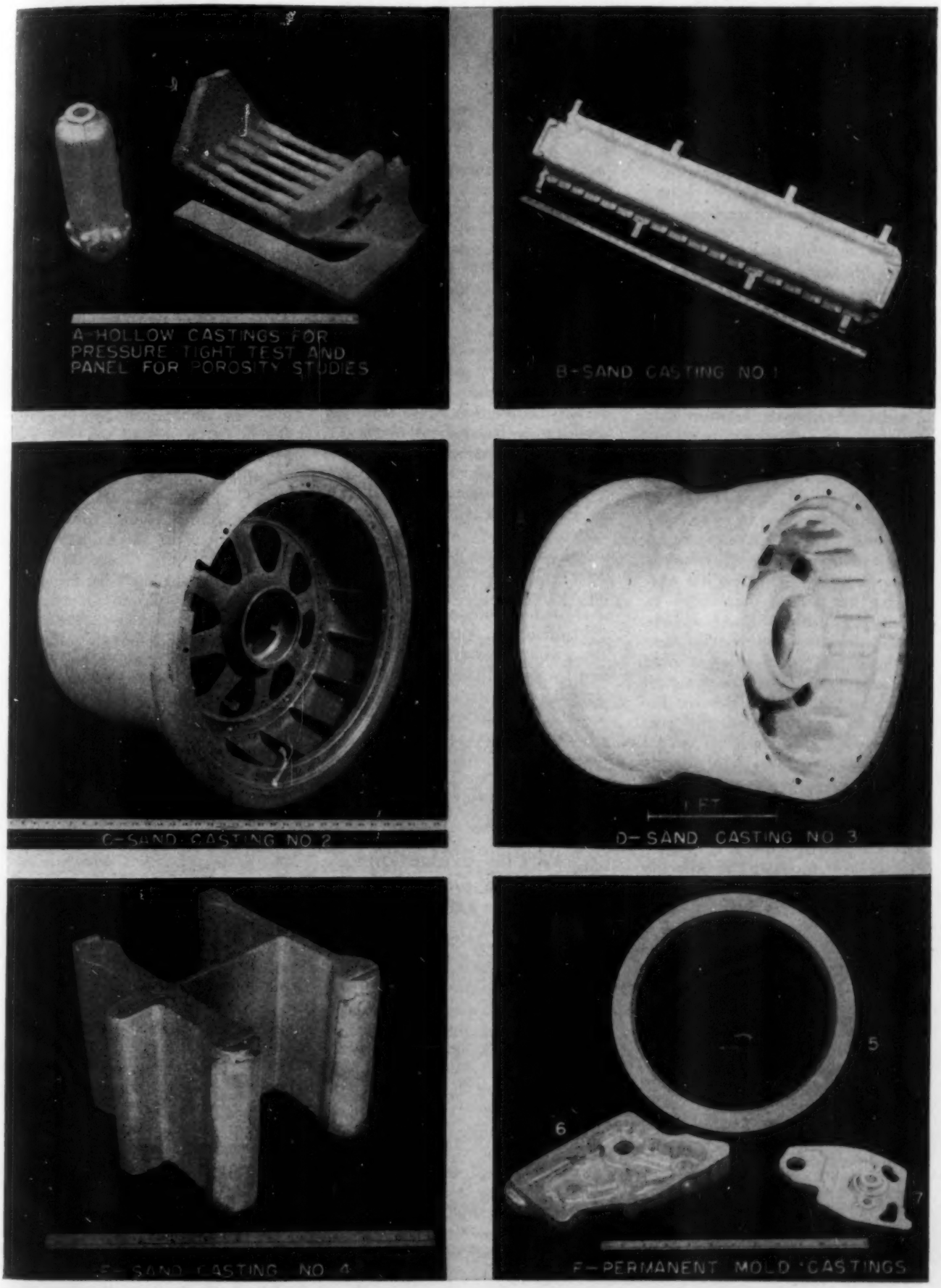

Fig. 2—Types of magnesium alloy castings used for the various tests.

tion heat treatment. Zero (0) refers to no germination.

It should be kept in mind that the occurrence of germination is an abnormal phenomenon and is avoidable in all of these casting compositions by correct chilling and molding conditions, care in handling the castings after shake-out to avoid cold work, and the use of the proper solution heat treatment method[13].

Commercial Heat Treatments

Heat Treatability. This behavior of the alloys is expressed by the number of hours at the proper temperature to give a commercially acceptable degree of homogenization. These are commercial treatments and the temperatures used were selected to provide a compromise between time for treatment and avoidance of fusion voids and sagging. A compound rating of 4 or less is considered satisfactory[14].

It is common practice to give the "H" and "C" (high zinc type) alloys a 2-hr. pretreatment over the range from 500° F. up to the heat treating temperature in order to avoid fusion of the lower melting phases prior to the regular heat treating step. These two hours should be added to the time for the high zinc compositions, since the low zinc alloys do not require this pretreatment.

The specific temperature of 500° F. is not chosen for metallurgical reasons, but for production convenience. This temperature should not be higher than 640° F. In practice the 2-hr. preheat has little significance, since most large production furnaces require at least that long to reach heat treating temperatures after unloading and reloading with a cold charge.

It can be seen from Table 4 that addition of zinc will increase the rate of homogenization of Mg-Al-Mn alloys. Thus, "R" alloy, with 9 per cent Al and 0.7 per cent Zn, requires 18 hours at 780° F., while C alloy, also with 9 per cent Al but 2 per cent Zn, can be equivalently heat treated 10° F. lower in the same length of time. The significance of this 10° F. drop is shown by the fact that the time necessary for heat treatment of "R" alloy is about doubled when the temperature is 770° F.

A qualitative rating of the tendency of the various alloys to sag during the solution heat treatment suitable to each alloy is given, one (1) being the least amount of sagging. This was obtained by supporting a test bar of each composition during its standard heat treatment as a loaded cantilever beam and then noting the relative permanent deflection. In general, with each alloy this sagging tendency is proportional to the temperature.

Weldability. The figures given are a qualitative rating of the ease with which these alloys may be welded, one (1) being the best. The low zinc containing alloys show less tendency to crack at the bead during welding.

Machinability. There are no significant differences in these alloys. All have excellent machinability.

Part II—Evaluation

As has been previously pointed out, this section will deal with interpretation of the data presented and may, therefore, be considered with the thought that the conclusions reached represent opinion based on experience; other circumstances might lead to somewhat different conclusions.

It must first be recognized that all of these alloys are compositions within one system—Mg-Al-Mn-Zn. Therefore, many of the physical and mechanical properties are interdependent, and all of them change in a gradual manner from one alloy to another.

Equivalent mechanical properties can be secured with Mg-Al-Mn or by adding Zn and reducing the aluminum proportionately. Any selection of a specific composition is thus somewhat arbitrary within the general framework of the system as a whole.

Examination of Table 2 reveals that, within the alloy system with which we are dealing, two general classifications of mechanical properties exist. First, there are those alloys possessing high hardness and strength, but with somewhat limited ductility and toughness. These are compositions containing a relatively high total alloy content ($>$ 10 per cent).

Second, there are those alloys having high ductility and toughness, though somewhat lower hardness and strength. These compositions are characterized by a lower total alloy content ($<$ 9 per cent). Within each of these classes a further choice concerning the ratio of Zn/Al can be made.

For the high strength, high hardness class it is concluded that the most suitable composition is "C" alloy. This conclusion is reached because "C" alloy is relatively good in soundness, weldability, and corrosion, and responds uniquely to special quenching and aging heat treatment procedures[15].

Thus, in this range of possible compositions neither a high nor a low Zn/Al ratio is chosen, but rather a uniquely good compromise. However, if soundness as such is the prime requisite, dropping the Zn and raising the Al is a commercially successful and demonstrated alloy (e.g., "G" alloy).

In the low total alloy range no such fortunate compromise has been found and we must, therefore, compare high zinc (3 per cent) and low

Table 4

FOUNDRY CONSIDERATIONS

	Alloy				
	"C"	*"H"*	*"R"*	*"G"*	*"A"*
Liquidus, ° F.	1106	1135	1110	1100	1120
Freezing Range, ° F.	310/350	250/450	275/320	260/300	225/275
Fluidity (A.F.A. in.)	30	25	26	26	23
Castability	1	1	1	1	1
Pattern Shrinkage, in./ft.	5/32	5/32	5/32	5/32	5/32
Melting Loss, per cent	2.5	2.0	3.0 (est.)	3.5	3.0 (est.)
Porosity Tendency	2	4	1.5	1	1
Pressure Tightness	2	3	1	1	1
Hot Cracking Tendency	1	2	1	1	1
Cold Brittleness	3	1	2	4	1
Grain Size	Fine	Fine	Fine	Fine	Fine
Germination Tendency	3	0	3	4	2
Heat Treat (hr. at ° F.	18/770	10/730	18/780	18/780	16/790
Heat Treat Sagging	3	1	2	2	2
Weldability (Hot)	2	3	1	1	1
Machinability	Excellent	Excellent	Excellent	Excellent	Excellent

zinc alloys. The mechanical properties of these alloys, as shown in Table 2, are too much alike to permit selection on this basis.

We are, therefore, privileged to make a choice on the basis of the more qualitative factors listed in Table 4, reference to which reveals that appreciable differences exist in six properties: porosity tendency or pressure tightness, hot cracking tendency, germination, heat treatability, weldability, and salt water corrosion.

Permanent Mold Castings

Of these, the high Zn/Al ratio type is superior in three cases (germination, heat treatability, and salt water corrosion), while the low Zn/Al ratio type is superior in the remaining three (porosity tendency, hot cracking tendency, and weldability). The question of relative importance of these properties must be examined.

One of the characteristics—hot cracking tendency—need be considered only in connection with a permanent mold type of casting. There it is of sufficient importance to rule out a high Zn/Al ratio for any but the simplest of shapes. Thus, for permanent mold, in general, the choice of alloys should be "C" alloy for high strength and a low Zn alloy (e.g., "A" alloy) for toughness.

Since hot cracking is not a limiting factor in the sand foundry, this property can be neglected in selecting an alloy for this type of fabrication. Thus, a balance must be made between the importance of low porosity tendency and good weldability on one hand, and low corrosion sensitivity to impurities, ease of heat treatment, and no germination on the other hand. Emphasis upon one property or another is responsible for the choice of alloy for any particular application.

In order to check the properties of the metal found in commercial castings when poured in different alloy compositions, the four types of castings listed in Table 4 were made. With all four types of casting the "A" alloy was substantially more sound than the "H" alloy.

In spite of this the very interesting fact is apparent that in three of the four castings the properties of test bars cut from the castings—both tensile and fatigue—are equivalent for the "H" and "A" alloys. In the remaining casting (no. 3) the "H" alloy was sufficiently more porous than the "A" alloy in one section of the casting to lower the fatigue strength of test bars cut from the casting.

Porosity Control

There is no clear correlation of these test bar results with the serviceability of the casting. Porosity will have little influence in the practical matter of the serviceability of the casting, unless the porosity occurs in a location at which failure might initiate even if the metal were sound.

Control over the location of porosity is possible by the foundryman, but he does not always know which regions of the casting are to be the ones most critically stressed in service. An absence of radiographic porosity possesses certain psychological advantages and is of unquestioned value in those cases in which pressure tightness is a service requirement.

With alloy compositions containing more than 0.3 per cent zinc, there is a distinct increase in radiographic porosity[16]. Thus, although the mechanical properties of the low zinc alloys used by the British (0.4 per cent and 0.6 per cent Zn) are not significantly different from alloys containing no zinc, the advantage of the good soundness characteristics of the low zinc alloys is more fully obtained when the zinc is held to a maximum of 0.3 per cent.

Thus, while the term "low zinc" has been generally used in the discussion of this paper, this means preferably zero per cent Zn with an allowable maximum of 0.3 per cent.

Alloy Weldability

Weldability of casting alloys is a practical consideration which is of value both because of the adaptability of the castings to fabrication processes involving welding, and because of the economics of salvaging castings with small foundry defects.

Although salvage welding is not used, or used in only limited ways on aircraft castings, it should be at least as economically important in the peacetime commercial field as it is for steel foundries.

The atmospheric corrosion results in Table 2 emphasize the arbitrary nature of salt water corrosion testing. For exposures in a severe marine atmosphere the relative results obtained in a salt water alternate immersion test remain approximately true. However, for other more normal types of exposure, even in severe industrial atmospheres, both the high and low zinc types of alloy are quite similar in behavior.

Both are very stable, as shown by the fact that strength losses of bare metal in 4 years' exposure amount to only a few per cent. If painted, there is no loss in mechanical properties. Thus, the severity of the anticipated exposure determines how much emphasis should be placed upon salt water corrosion resistance.

Low Zinc Alloys

Low zinc alloys not of high purity grade are used for aircraft parts, wheels, engine parts, air frames, etc., by the English and the Germans with apparent satisfaction. In the military service in the United States a higher standard for salt water corrosion has been set and the high zinc alloys are specified for castings (and controlled high purity magnesium alloys for wrought metal products).

It has been shown[8] that if certain impurities are controlled high zinc is not necessary for salt water corrosion resistance. Controlled purity alloys, whether with high or low zinc, will have a corrosion rate of 0.2 mg/cm²/day in 3 per cent NaCl solution and will show no loss in mechanical properties under the coastal or industrial atmospheric exposures as listed in Table 2.

Care in paint protection schedules and in design to take care of contact with dissimilar metals and of pockets likely to trap water are most effective in securing good stability in service.

As can be seen from Table 4, the substitution of Zn for Al to maintain a constant total alloy content results in shorter times of heat treatment at a given or lower temperature. "H" alloy is considered the easiest to heat treat because it can be homogenized more rapidly and the temperature is low enough so that little trouble with sagging is experienced.

Difficulties that have been mentioned[2] are due to lack of close temperature control of the heat treating furnace, which control is desirable in any case. For the high zinc alloy mechanical properties are good without heat treatment, while

improved toughness may be obtained by a heat treatment which is easy and rapid. No special precautions against germination need be taken.

The high zinc type alloy should be of particular value in the secondary metal field because of its relatively greater tolerance for impurities.

The conclusion is reached that two alloys should be available in the ductile, tough alloy class. First, there is an alloy with low zinc characterized by soundness and good weldability. This composition should be used for critical parts and high quality, specialized work. The optimum composition within this class is represented by compositions of Al < 9 per cent, e.g., "A" alloy (maximum of 0.3 per cent Zn).

Second, there is an alloy with high zinc characterized by good tolerance for impurities together with good heat treatment characteristics. This alloy is ideally suited to low cost operation when soundness specification is not critical.

Secondary metal can be used. The optimum composition within this range is "H" alloy. When the criterion for serviceability is maximum resistance to salt water corrosion, the high zinc alloy is the presently available better choice.

Data on the physical and mechanical properties of the various common casting alloys as obtained from laboratory test bars and as actually found in typical commercial castings, together with information on how these alloys behave in foundry and fabrication processes have been presented.

Summary

It has been further pointed out that all of these alloys are essentially of one family—Mg-Al-Mn-Zn—and, therefore, their properties are interdependent. Since service requirements are different, no one composition will satisfy all the needs. In view of this fact and the importance to both foundry and fabricator of keeping the number of different alloys to a reasonable minimum, three compositions have been selected as suitable for most service requirements.

Since the mechanical properties seem to be substantially equivalent, the choice between high and low zinc alloys has been based upon other characteristics. Future research may show alloy differences in response to treatments, or in other mechanical properties which will affect serviceability and may, therefore, outweigh some of the qualitative or economic considerations leading to the following compositions:

1. For applications requiring maximum yield strength and hardness, only fair toughness, good soundness, and good salt atmosphere corrosion resistance, "C" alloy is indicated. This applies equally to sand and permanent mold castings.

2. For applications requiring maximum toughness, only fair hardness and yield strength, maximum soundness and weldability, a low zinc alloy with Al < 9 per cent, e.g., "A" alloy, is indicated. For maximum salt atmosphere corrosion resistance in this alloy, purity must be controlled. This applies equally to sand and permanent mold castings.

3. For general sand casting applications requiring maximum toughness, only fair hardness and yield strength, maximum salt atmosphere corrosion resistance and tolerance to impurities, "H" alloy is indicated.

The benefits of present alloy composition factors can be completely attained only after the best design and fabricating practices have been sought out and fully applied.

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A.F.A. HEAT TRANSFER COMMITTEE REPORT

A Committee of the Technical Development Program

Report of the Chairman

ON May 4, 1944, R. E. Kennedy, A.F.A. Secretary, notified Messrs. H. A. Schwartz, National Malleable & Steel Castings Co., Cleveland; E. C. Troy, Dodge Steel Co., Philadelphia, and H. F. Taylor, Naval Research Laboratory, Anacostia, Washington, D. C., that they had been appointed a committee to consider the desirability of A.F.A. sponsorship for an investigation, or investigations, along the general line of the paper "Heat Flow Problems in Foundry Work," presented at the Buffalo meeting (1944) of the Association by Dr. Victor Paschkis, Columbia University, New York City.

This committee considered the matter and recommended the formation of a standing committee on heat transfer to consider problems in that field from the viewpoint presented by Dr. Paschkis, and from such other viewpoints as might seem desirable.

The matter was submitted to the Board of Directors at its meeting July 12, 1944, and the formation of such a committee was approved. Those appointed were the three members of the original investigating committee, and Messrs. K. L. Clark, Naval Research Laboratory, Washington, and John B. Caine, Sawbrook Steel Castings Co., Lockland, Ohio. Contact was made very promptly with Dr. Paschkis and he has since worked with the committee as a consulting member.

Method of Attack

It was recognized that if the heat analyzer data confirmed the results of other types of experimentation, it would be desirable to transfer most problems of heat transfer to Dr. Paschkis' laboratory at Columbia University rather than to engage in the expense of carrying on bleeding tests and similar observations in steel foundries.

It seemed, therefore, necessary in the first instance to determine whether the thermal constants requisite to the solution on the heat analyzer, and pertaining both to the metal being cast and to the mold material, were sufficiently well known to warrant the approach to practical problems through the heat analyzer laboratory.

Little doubt was entertained by anyone that the fundamental mathematical principles of heat transfer were correctly known and that the heat analyzer could solve the corresponding equations with sufficient accuracy for practical use. The question of the selection of constants, however, was a subject of considerable doubt.

Selection of Material for Study

The committee decided, as its first project, upon a study of the rate of freezing of flat plates in a foundry, and a comparison of the results so observed with the results calculated from the best acceptable data on the heat analyzer.

Steel was selected as the metal to be cast and to be used as chills because the thermal data for one particular steel seemed to be better known than any other material suitable for experimentation. The flat slab was selected as the test body because the mathematics of the problem is the simplest possible, so that no argument could arise as to the theoretical basis of the comparison.

Cooperative Experimentation. The members of the committee who are on the staff of the Naval Research Laboratory kindly secured permission to make the practical tests there. Dr. Paschkis undertook the parallel investigation in the Columbia University laboratory; in part at the expense of the American Foundrymen's Association. Columbia University very generously contributed aid to the project by matching the amount of work paid for by A.F.A. with an equal amount conducted with University funds.

Through Dr. Paschkis' contact with the U. S. Steel Corp. Laboratory, Kearney, N. J., he was able to secure certain thermal data for a steel containing approximately 0.2 per cent carbon to serve as a basis of calculation, and this steel was accordingly selected for the foundry experiments at the Naval Research Laboratory also.

The committee and A.F.A. are indebted to those who have contributed in various ways to the furtherance of the project as indicated.

The Report

In view of the requirements of Naval procedure, it is necessary for this committee to break up the technical portion of its report into two sections. The first section is a paper by K. L. Clark, Naval Research Laboratory, entitled "Methods Employed to Obtain Rates of Solidification by Direct Experiment." This paper covers the work done at Anacostia.

The second section is a paper by Dr. Paschkis entitled "Studies on Solidification of Castings." Dr. Paschkis has availed himself of the observations contained in the paper by Clark, from which he has quoted freely.

These two papers accompany the present report, and the report and the two papers are to be considered as a single publication covering the work of the Heat Transfer Committee.

Recommended Future Investigations

With respect to work in the future, Dr. Paschkis has outlined the following, which has had the general approval of the committee, but no details have been formulated:

"Without attempting to give a program covering the entire field which eventually should be investigated, the following is a list of the desirable next steps of investigation. Item *E* could be carried out simultaneously with items *A* to *D*.

"*A*. Determine the air gap time by observing steel temperatures. These experiments should be carried out with the same dimensions of

castings as used in the present experiments. A correlating investigation on the heat and mass flow analyzer is necessary.

"*B.* Carry out similar tests on freezing of cylindrical bodies. Here again there should be correlating tests between direct experiments and experiments by electric analogy method.

"*C.* Carry out similar tests for spheres. Because of the difficulty of casting, these experiments would be carried out only by the electric analogy method. Knowledge of the freezing rates of spheres is important for two reasons:

(a) Chworinoff[6] states that freezing is characterized definitely by the ratio of volume to area of contact between casting and mold. This statement could be checked after the values for slabs, cylinders, and spheres are available.

(b) For the general information desired, it will also be necessary to obtain data on freezing for spheres, with the thought in mind that in irregularly shaped castings having portions similar to spheres, such portions will follow the same freezing laws as spheres.

"*D.* On the heat and mass flow analyzer it is possible to determine which of the thermal properties of casting, chill and sand are of major importance. Such an investigation would make it possible to reduce the number of investigations recommended in the next number.

"*E.* Analyses by mathematical approach as well as by the electric analogy method are based on a knowledge of the thermal properties. Inasmuch as these are not known accurately, it would be desirable to have them established in properly equipped laboratories. The properties involved are: (a) for the casting, (1) thermal conductivity, (2) density, (3) heat of fusion, and (4) temperature range of fusion; (b) for chill and sand, (1) specific heat, (2) density, and (3) thermal conductivity. All values should be determined from ordinary atmospheric temperatures to the temperatures which the various materials reach in foundry practice."

H. A. SCHWARTZ, *Chairman*,
HEAT TRANSFER COMMITTEE.

Methods Employed to Obtain Rates of Solidification

By K. L. Clark, Naval Research Laboratory, Washington, D. C.

THE technique which was employed to obtain rates of solidification by direct experiment was that of "slush-casting" or "bleeding." The castings were poured and the flasks were then overturned at selected time intervals after pouring. The solidified shells were sectioned and measured to provide data for showing the relationship between thickness of solidified skin and time.

Mold Preparation. The molds were made with an A.F.A. No. 70 washed silica sand which was bonded with 3 per cent western bentonite, 0.5 per cent corn flour, and 1.5 per cent foundry dextrin (all percentages by weight of the dry mixture). The sand was tempered with approximately 4 per cent water and was rammed with pneumatic rammers. All molds were oven-dried at 400° F. for at least 20 hours.

It originally was thought that the presence of cereal binders in the sand mixture might alter the solidification characteristics of the metal because of gas generation. Therefore, several comparative experiments at different bleeding times were made in which the above mixture was used for one-half of the mold and a mixture containing only clay bonding material was used for the other half. If there was any difference in thickness of the solidified walls for any bleeding time, it was well within the accuracy of measurement.

In all cases, the slabs were molded vertically and full length risers were superimposed upon them.

Chill Practice. All chills were cast of the same material which was used for pouring the experimental castings. Such practice was followed because the thermal properties of this particular composition have been more carefully determined than those for other compositions. The surfaces of the chills were prepared by sand blasting prior to their insertion in the molds.

Melting Procedure. For all castings, except those having a thickness of 6 in., steel was made by melting sheared ingot iron in a 300-lb. induction furnace, adding ferrosilicon, ferromanganese, and wash metal, and deoxidizing in the ladle with 0.1 per cent aluminum. The additions were adjusted to produce a steel having a composition of approximately 0.2 per cent carbon, 0.3 per cent silicon, and 0.5 per cent manganese.

Steel for the 6-in. castings was melted from selected foundry return scrap in a ½-ton basic, electric arc furnace with the same final deoxidation practice; additions were adjusted to produce a steel of the same approximate composition given in the foregoing.

Temperature control was exercised by pouring the molten metal into the ladle at 50 to 100° F. above the desired casting temperature, where it was held until the proper temperature was reached. Temperature measurements were made with an optical pyrometer sighted upon the end of a closed-end refractory tube which was immersed to approximately 4 in. below the surface of the metal in the ladle.

Pouring. Steel was poured from the ladle into the mold through a baked sand runner-cup which was placed on the mold near one end of the mold cavity and located so that the metal stream impinged directly upon the bottom of the cav-

Table 1

Thickness of Solidified Steel (0.2 Per Cent C) as Measured at the Mid-point of the Face of 2 x 6 x 6-in. Castings, Indicated Time After Pouring

No.	Wall Thickness, in.	Time, sec.	Pouring Temperature, ° F.
Sand Mold—No Chills			
P6	0.19	21	2845
P7	0.25	40	2900
P8	0.44	60	2900
P9	0.59	123	2880
P10	0.83	181	2850
Sand Mold—1½-in. Chill on Each Side of Plate			
PC6	0.68	38	2840
PC7	0.55	23.5	2815
PC8	0.63	34	2810
PC9	0.75	45	2880
PC10	0.86	52	2810

Table 2

Thickness of Solidified Steel (0.2 Per Cent C) as Measured at the Mid-point of the Face of 4 x 8 x 8-in. Castings, Indicated Time After Pouring

No.	Wall Thickness, in.	Time, sec.	Pouring Temperature, ° F.
Sand Mold—No Chills			
P1	0.19	31.5	2865
PO4	0.20	32	2850
PO9	0.27	60	2833
P3	0.50	122	2900
PO11	0.48	120	2840
PO10	0.68	245	2840
PO20	0.70	242	2858
PO21	0.85	302	2831
PO18	1.03	361	2815
PO17	1.25	480	2849
Sand Mold—3-in. Chill on Each Side of Plate			
PC1	0.52	20	2810
PC2	0.77	43	2880
PC3	0.92	63	2810
PC4	1.38	123	2815
PC5	1.67	181	2840

Table 3

Thickness of Solidified Steel (0.2 Per Cent C) as Measured at the Mid-point of the Face of 6 x 12 x 12-in. Castings, Indicated Time After Pouring

No.	Wall Thickness, in.	Time, sec.	Pouring Temperature, ° F.
Sand Mold—4½-in. Chill on Each Side of Plate			
1-1	0.75	44	2900
1-2	0.94	63	2885
2-1	1.34	120	2950
2-2	1.67	184	2930

Table 4

Temperature Measured in Sand Adjacent to Mid-Point of the Face of a 2 x 6 x 6-in. Steel Casting at Indicated Time After Pouring (Pouring Temperature—2850° F.)

⅛-in. from Metal Interface		¼-in. from Metal Interface		¾-in. from Metal Interface		1-in. from Metal Interface		2-in. from Metal Interface	
Time, sec.	Temp. ° F.	Time, sec.	Temp. ° F.	Time, sec.	Temp. ° F.	Time, sec.	Temp. ° F.	Time, sec.	Temp. ° F.
30	1158	60	885	30	87	60	94	30	63
210	2167	180	1659	90	245	180	225	210	77
270	2232	240	1806	150	435	300	423	390	145
330	2266	360	1956	330	925	420	597	480	171
390	2280	420	2005	450	1150	540	754	600	190
450	2280	480	2025	510	1241	720	941	720	234
510	2271	540	2089	570	1315	840	1025	960	327
570	2255	600	2090	660	1396	960	1090	1200	417
660	2225	720	2030	780	1465	1080	1139	1440	461
900	2126	840	2004	900	1504	1200	1176	1560	517
1140	2035	960	1971	1140	1536	1440	1225	1800	565
1380	1956	1200	1904	1260	1540	1560	1238	2040	617
1620	1886	1560	1813	1500	1540	1680	1247	2160	646
1860	1825	1920	1735	1740	1522	1800	1255	2400	660
2100	1773	2040	1710	1860	1513	1920	1260	2520	675
2340	1722	2280	1668	2100	1491	2160	1261	2640	687
2580	1676	2520	1625	2340	1467	2400	1257	2760	701
2820	1636	2760	1585	2580	1445	2640	1250	2880	710
2940	1615	3000	1551	2820	1421	2880	1241	3000	720

ity. In all cases, an attempt was made to keep the runner-cup filled and the ladle-lip at the same height (minimum possible distance) above the cup.

Timing Solidification. Stop-watches were started when the slab sections were observed to be half filled and were stopped when the molds were overturned. Thus, the solidification times were arbitrarily taken to be those times during which the metal was in contact with the mold at the point where skin thickness measurements were to be made.

Skin Measurements. All castings were sectioned in such a manner that the skin thickness measurements could be taken at the centers of the large faces. In some cases the internal walls were sufficiently smooth and uniform to allow the use of micrometer calipers. In other cases, particularly with the sand-cast plates which were bled after relatively long time periods, the internal faces were somewhat roughened; these walls were gauged as closely as possible with machinists' outside calipers and measured to the nearest sixty-fourth of an inch.

Mold Temperatures. Temperatures within the molding materials were determined by inserting chromel-alumel thermocouples parallel to the mold-metal interface at selected distances therefrom, and readings were taken at regular time intervals. These data were plotted to obtain the family of curves which are shown as alternate dashes and dots on Fig. 13 of Dr. Paschkis' paper.

Table 5

Temperature Measured in the Chill 3 in. from Its Interface with a 4x8x12-in. Steel Casting at Indicated Time After Pouring (Total Chill Thickness—3½-in.; Pouring Temperature—2900° F.)

3 in. from Casting-Chill Interface		3 in. from Casting-Chill Interface	
Time, sec.	Temp., ° F.	Time, sec.	Temp., ° F.
30	70	1500	1130
120	130	1680	1165
240	340	1920	1190
360	515	2190	1210
480	650	2400	1220
600	750	2640	1230
720	840	2880	1230
840	915	3120	1230
960	970	3360	1225
1200	1035	3600	1220

The data which appear in the Tables 1 to 5, inclusive, were obtained by Nicholas Kowall, Naval Research Laboratory.

Note: *The paper by Dr. Paschkis, the second section of the Heat Transfer Committee Report, begins on the following page.*

Studies on Solidification of Castings

By Dr. Victor Paschkis*, Columbia University, New York City

THIS paper together with the preceding one is to be considered as one unit. The experiments reported upon were carried out in close contact with the Naval Research Laboratory committee members and frequent conferences were held.

The rate of freezing during solidification of castings is a point of great significance in the art of casting. In certain alloys, particularly cast iron, the rate of solidification is effective in determining the structural characteristics of the frozen metal. In some alloys, the rate of solidification determines the occurrence or absence of interdendritic shrinkage. In castings of most alloys, susceptibility to gross shrinkage is determined by the combination of mold configuration and solidification rates at various locations in the mold.

Solidification Variables

Variables in Problem. Rational analysis of solidification is, therefore, very desirable but, so far, has been lacking because of the complexity of the problem. The following variables seem to be of major importance in connection with the solidification of castings:

1. Nature and thermal properties of the materials involved (casting, possible chills, and mold).
2. Geometry of the casting and the mold.
3. Pouring temperature (in case of gray iron, this influences the formation of graphite flakes and thereby influences the thermal properties along with the mechanical properties of the casting).
4. Speed of pouring.
5. Formation of an air gap between casting and mold because of shrinkage of the casting.

The large number of variables makes a step by step method of analysis necessary, eliminating some of the variables at first, that is, by keeping some of them constant. In this investigation, the speed of pouring and, with one exception, the pouring temperature were held constant. Only one shape was investigated; however, different sizes of this shape were tested. The present experiments deal exclusively with casting of steel.

Approach to Problem. Recognizing the fact that the art of casting can be put on a more rational basis only if more adequate information concerning the various aspects of solidification is available, it was deemed necessary to look for an economic tool of research for the large scale investigations which would be required.

The conventional way of direct experimentation[1, 2] was considered and found to be extremely expensive and subject to so many difficulties as to make it troublesome to obtain extensive information. The electric analogy method incorporated in the heat and mass flow analyzer at Columbia University gave promise of being a more economical tool of research. This method has been tested time and again and has been described previously in a publication of this Association[3]. In this previous description, further literature on the method is quoted.

Comparative Experiments

Because of the complexity of the problem of solidification, it seemed necessary first to have direct proof that the electric analogy method would be suitable for solution of this type of problem. This answer could be found only through comparative experiments in which actual foundry work was compared with results obtained on the heat and mass flow analyzer. The present report covers such comparative experiments†.

End Point of Investigation. The tests reported hereafter, therefore, serve two purposes. First, they shed some light as to the validity of using the heat and mass flow analyzer in connection with solidification problems; second, they are a first step toward obtaining general information on the solidification problem. In calling this work a first step, the author does not want to detract from the value of previous work.

In addition to the work of Yearley[1] and Troy[2], investigations by Briggs and Gezelius[5] should be mentioned; attention is also drawn to the exhaustive study by Chworinoff[6] and to the work of the (British) Iron and Steel Institute[7]. There are many more publications on this subject, some of which are quoted in the above references.

Investigation Material

If in the light of all this previous work, the author still speaks of this paper as a first step, it is done in the hope that eventually a complete and consistent set of data can be assembled by the A.F.A. Heat Transfer Committee which will cover the entire field of solidification. In this connection, reference is made to the general report of the committee, in which next steps for such a program are discussed.

Selection for Cast Material for Investigation. In selecting the steel for which the investigations were carried out, the author was guided by the necessity of finding a material whose properties were established well enough for such a comparative test. The selected steel was of 0.2 per cent carbon; the properties are shown in various handbooks and publications and seem to check reasonably well.

As explained previously, the report serves in part to compare the results obtained by the method of direct experimentation with those obtained by electric analogy. Generally it was attempted to find two types of information: (1) The thickness of frozen steel expressed as a function of freezing time, and (2) the temperature-time function of the casting, chill, and sand.

The experiments carried out on the heat and mass flow analyzer

*Research Associate in charge of Heat and Mass Flow Analyzer Laboratory, Department of Mechanical Engineering.

†In the present report, experiments on the heat and mass flow analyzer are described and their results are compared with those obtained in direct experiments. The latter, carried out at the Naval Research Laboratory, are described in the preceding paper by K. L. Clark.[4] Whenever, in this paper, "direct experiments" are mentioned, reference is made to this article.

consisted of building up an electrical circuit to represent thermal conditions within the casting and adjacent mold material, and carrying out certain electrical measurements which were then translated into heat terms. The technique of this approach is described in Appendix 1.

Experiments

Program. In selecting the shape to be investigated, the author was guided by the desire for simple experiments. Due consideration also was given the desirability of simplicity of the direct experiments carried out simultaneously. With this purpose in mind, a slab was selected having a surface area so large that the effect of the ends was completely negligible at the center.

The experiments with chills were carried out so that the large side of the casting was cast against the chill and only the narrow sides were exposed to sand. The chill was in all cases backed by sand. It was desired under all circumstances to have "adequate chills"; i.e., chills which at the end of the freezing period were not entirely saturated with heat. In symetry, both faces were chilled when chills were used*.

Based on these considerations, the dimensions shown in Tables 6 and 7 were selected. Appended to each dimension is a designation of the experiment.

In the direct experiments, sand thicknesses different from those selected and indicated in the table were used. In the direct experiments in casting in sand, the thicknesses were 5 in. for experiment S_2 and 7 in. for experiment S_4. Therefore, in the electric experiments, the originally selected thicknesses also were changed to 5 in. for S_2 and 10 in. for S_4. All castings were poured at a temperature of 2845° F., with one exception where a temperature of 2950° F. was used.

Solidification Curves. The solidification of the castings is shown by curves in which times are plotted as abscissas and frozen thicknesses are plotted as ordinates. For example, an abscissa of 200 sec. and an ordinate of 0.64 in. indicates that after 200 sec. a thickness of 0.64 in. was frozen on each wall of the casting for which the curve holds.

The various figures apply to the different experiments listed above. In each figure, several curves are shown. The constitution diagrams of the steel show a freezing range of 100° F., namely from 2700 to 2600° F. In the direct experiments by bleeding, only one curve of solidification is obtained, but in the electric experiments two curves are obtained, one for beginning of freezing and one for end of freezing.

There was some question as to which curve should be considered comparable to the curve obtained in direct experimentation. After careful consideration, it was decided that the solidified thickness measured in the bleeding tests corresponds to the beginning of solidification. For the direct experiments, the observed points are inserted in the figures.

Both curves (beginning and end of freezing) are shown in the diagrams. There is as yet no information available concerning the time of formation of the air gap. Therefore, in some instances, curves are shown with different values of time of formation of the air gap. The way in which the air gap actually forms is not well established. The author used the concept, which may be an oversimplification, that the air gap forms suddenly. This implies that, up to the time of the formation of the air gap, there is intimate contact between the casting and the surroundings (chill or mold), whereas after the time of formation of air gap, there is a finite distance between the two faces.

Actually, it is probable that the air gap does not form at all points at the same time. Local differences in mold or chill may account for local changes in formation of air gap and the gradual rise of the metal in the mold could account for a systematic difference in air gap time at the top and the bottom of the mold. For the present experiments, it was assumed, however, that such differences do not occur and that the air gap opens suddenly. Table 8 lists the figures along with pertinent information concerning the presented data.

*In several of the curves presented, diagrams showing the relative amounts of metal, chill and sand are shown. In these instances, the thickness of the steel shown does not correspond with the amount shown in the legend. Since both sides of the slab were chilled, and since each chill extracts heat from half the slab, the diagram indicates only half the mold and hence half the metal thickness.

Table 6

Dimensions of Castings Made in Sand

Experiment	Thickness of Slab, in.	Total Dimension of Slab, in.	Thickness of Sand, in.
S_2	2	2x6x6	4
S_4	4	4x8x8	8

Table 7

Dimensions of Castings Made with Chills

Experiment	Thickness of Slab, in.	Total Dimension of Slab, in.	Thickness of Chill, in.	Thickness of Sand, in.
C_2	2	2x6x6	1½	2½
C_4	4	2x8x8	3	5
C_6	6	.....	4½	7½

Table 8*

Index to Freezing Rate Graphs

Figure	Experiment	Pouring Temperature, ° F.	Curves Shown	Remarks
1	S_2	2845	SA, SNA, EA, ENA	a
2	S_4	2845	SA, SNA, EA, ENA	a
3	S_4	2950	SNA, ENA	
4	C_2	2845	SA, EA	a
5	C_4	2845	SA, EA	a
6	C_6	2845	SA, EA	a

*In this table, *S* designates start of freezing (2700° F.) and *E*, end of freezing (2600° F.), *A* air gap, *NA* no air gap.
[a] Indicates that results from direct experiments are available.

Table 9

Index to Graphs Showing Temperatures in the Castings

Figure	Experiment	Air Gap, sec.	Pouring Temperature ° F.
7	S_2	no	2845
8	S_4	no	2845
9	S_4	20	2845
10	C_2	9	2845
11	C_4	36	2845
12	C_6	81	2845

Temperature-Time Relationships

The temperature-time relationships for the casting and for the surrounding medium were studied separately.

Casting. Table 9 lists the figures along with pertinent information concerning the presented data.

In each figure, several curves are

shown, each curve representing a different point in the casting, the limiting curves being those for the interface and the center of the slab, respectively. Times are plotted as abscissas, temperatures as ordinates.

Chill and Sand. Chill temperatures were found by direct measurements in earlier experiments carried out in the Naval Research Laboratory (personal communication by H. F. Taylor and K. L. Clark). Because of the close similarity of conditions, the values are included in the present experiments. Table 10 lists the figures along with pertinent information concerning the presented data.

In each figure, several curves are shown, each curve representing a different point in chill and/or sand.

Discussion of Results

Air Gap Times. Before comparing the results obtained by direct experiments and the electric method, it is necessary to consider the influence of the air gap. Systematic investigations were made for experiment C_4, in which various air gap times were used. The experiments of this group are summarized in Fig. 19. In this figure, the start of freezing at the center of the casting is plotted on the ordinate axis and the air gap times are plotted as abscissas.

The very marked influence of the air gap time is obvious. With an air gap time of 9 sec., the center starts to freeze 270 sec. after pouring, whereas with no air gap (which is equivalent to an air gap time equal to infinity) freezing at the center starts 146 sec. after pouring. The freezing time, therefore, is reduced approximately 45 per cent if the air gap time changes from 9 sec. to "no air gap."

Similar influences are to be seen in Figs. 5 and 6, where results for two different air gap times are shown.

For casting in sand, however, the air gap seems to have only a small influence on the rate of freezing. See, for example, Figs. 1 and 2 in which experiments with and without air gaps are compared. In Fig. 1, it can be seen that the freezing time of the center with 5 sec. air

Table 10

INDEX TO GRAPHS SHOWING CHILL AND SAND TEMPERATURES

Figure	*Experiment*	*Air gap, sec.*	*Pouring Temperature, ° F.*	*Remarks**
13	S_2	5	2845	x
14	S_1	no	2845	....
15	S_1	20	2845	....
16	C_2	9	2845	....
17	C_4	36	2845	x
18	C_6	81	2845	....

* For experiments marked "x", refer to direct experiments (See reference 4 in bibliography at end of report).

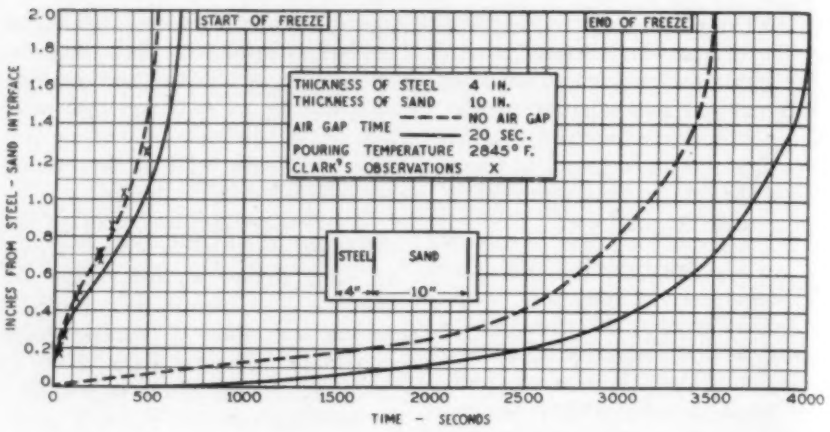


Fig. 2—Rate of freezing in 4-in. thick slab casting showing effect of air gap time.

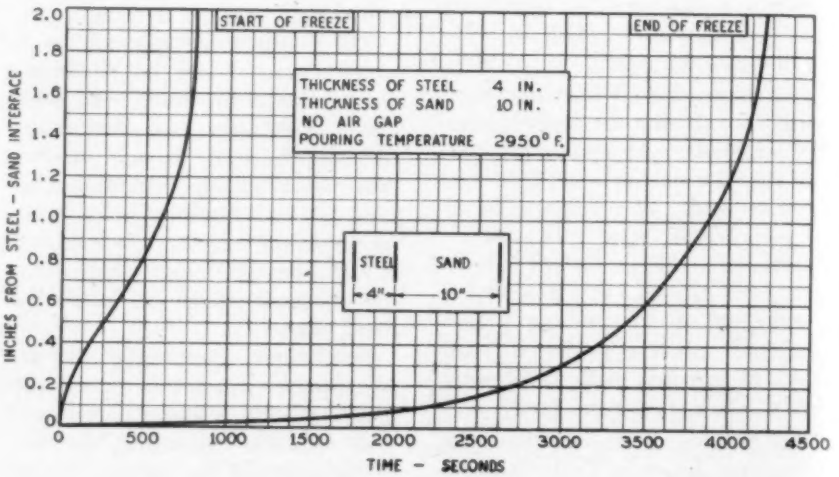


Fig. 3—Freezing rate of 4-in. thick slab casting poured at higher temperature (2950° F.) than used in Figs. 1 and 2. Compare with Fig. 2 for effect of pouring temperature.

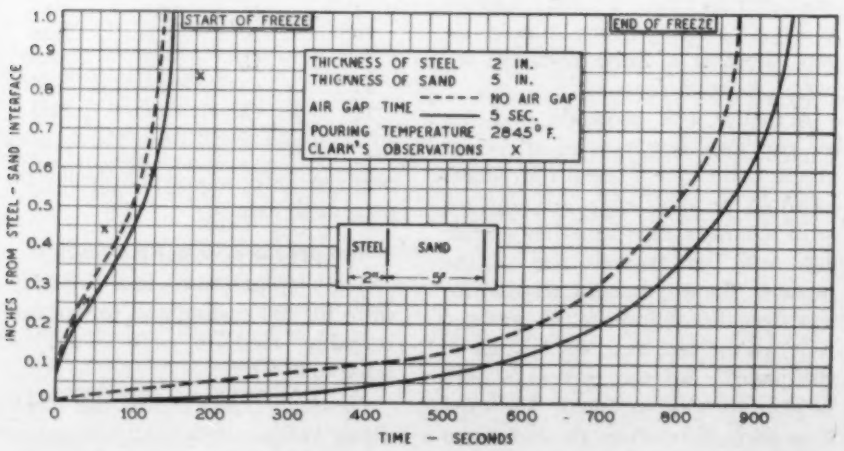
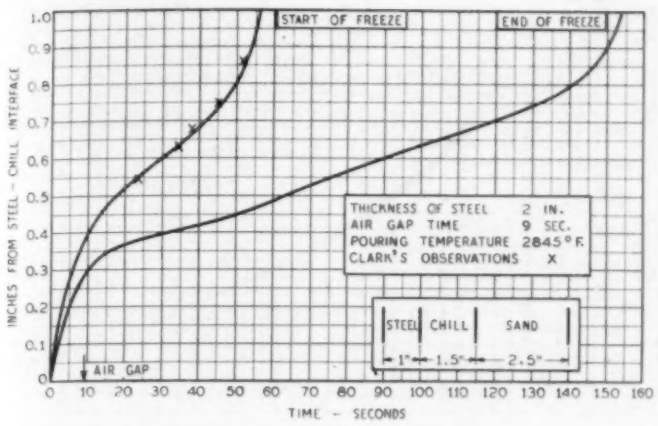


Fig. 1—Rate of freezing in 2-in. thick slab casting showing the effect of air gap time.



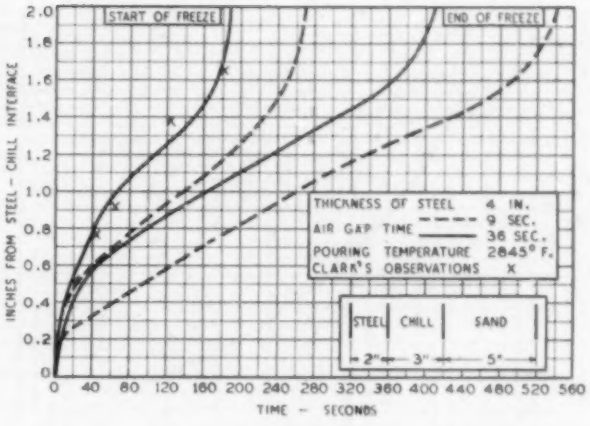


Fig. 4 (Left)—Effect of 1½-in. chill on freezing rate of 2-in. slab casting. Fig. 5 (Right)—Effect of 3-in. chill and air gap times on freezing rate of 4-in. slab casting.

gap time is only about 10 per cent higher than with no air gap. In the case of Fig. 2, the change is slightly larger but still at different order of magnitude as compared with chill experiments.

A word of justification is necessary concerning the selection of air gap times in the chill experiments (Figs. 4, 5, and 6). The times were selected so as to give as close a fit as possible to the curves obtained by direct experimentation. It appeared that such coincidence was obtained if the air gap times were changed proportionally to the square of the difference in thickness of the slab castings. The air gap time of the 4-in. steel is $2^2 = 4$ times as high as that for the 2-in. steel. The justification for this procedure will be given in the following after the other aspects of the experiment have been discussed.

The relationship found for the air gap formation time with chills also was applied in selecting the air gap formation times for sand experiments, and this is the reason that the air gap time for S_2 was 5 sec., or ¼ of the value used in experiment S_4.

Comparison of Freezing Times. From Figs. 1, 2, 4, 5, and 6, it is apparent that the curves "start of freeze" check closely with those found by direct experiments. This result should be considered separately for experiments in sand (S_2, and S_4) and for experiments in chill (C_2, C_4, and C_6). In sand, the influence of the air gap is so small that it safely may be neglected as far as freezing times are concerned and, therefore, in this connection the close check seems in itself a satisfactory proof of the validity of the electric analogy method.

In the chill experiments, the strong influence of the air gap time cannot be neglected. It should be pointed out here that the close check between direct and electric experiments could be the result of two assumptions which are mutually compensating. For example, the air gap time might have been incorrectly selected, but if the chill properties also would be incorrect, it is conceivable that correct results still would be obtained.

The probability of such a pair of compensating errors is small indeed in view of the number of experiments. It is still further lessened by the agreement in the chill temperatures discussed below. Therefore, the author feels that the present experiments indicate satisfactory coincidence between the two methods.

In Figs. 1, 2, 4, and 6, the individual points observed by Clark were plotted. By observing the individual points, it may be found that there is some choice as to how to draw the curves. There are not sufficient points to be quite sure about interpolation. Moreover, in view of the extreme experimental difficulties, one can really be sure of any point only if several experiments would have been bled after the same time and an average would be taken for the frozen thickness. Such procedure would of course call for a very great amount of experiments, more than it was possible to make.

The inflection in the curves can be explained as follows: When the hot steel comes in contact with the surface of the mold, it starts cooling at a certain rate. The heat of fusion, liberated as soon as the temperature reaches the upper limit of the freezing range, helps to maintain the temperature, and thus prevents the heat from layers further in to flow out. The freezing slows down and the curve bends towards the time

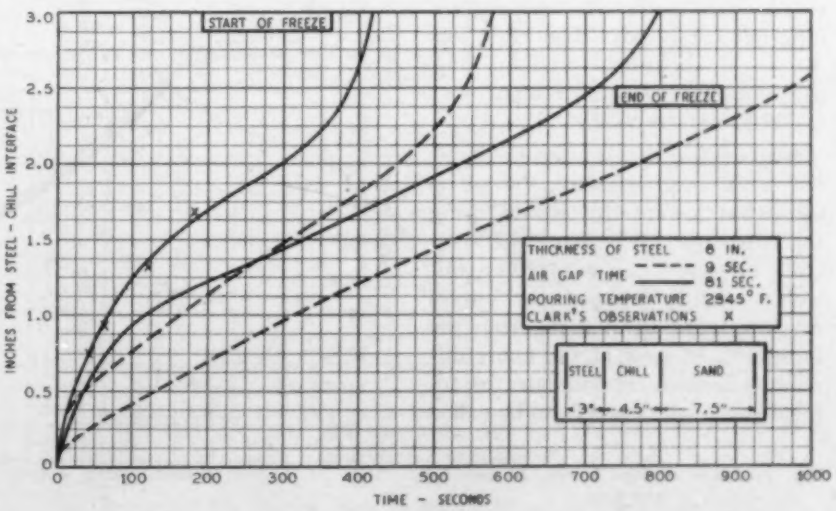
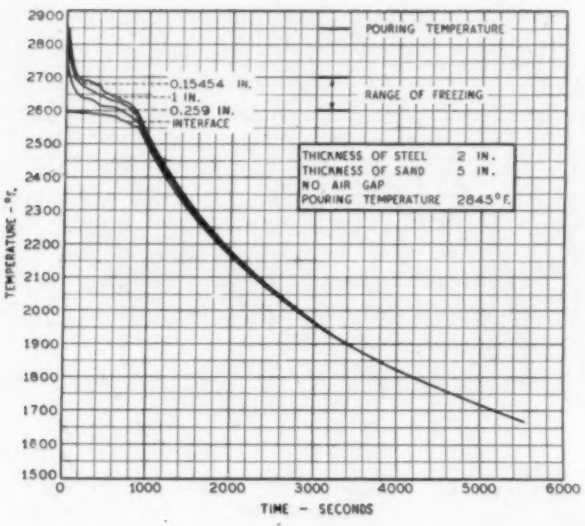


Fig. 6—Effect of 4½-in. chill and air gap times on freezing rate of 6-in. slab casting.



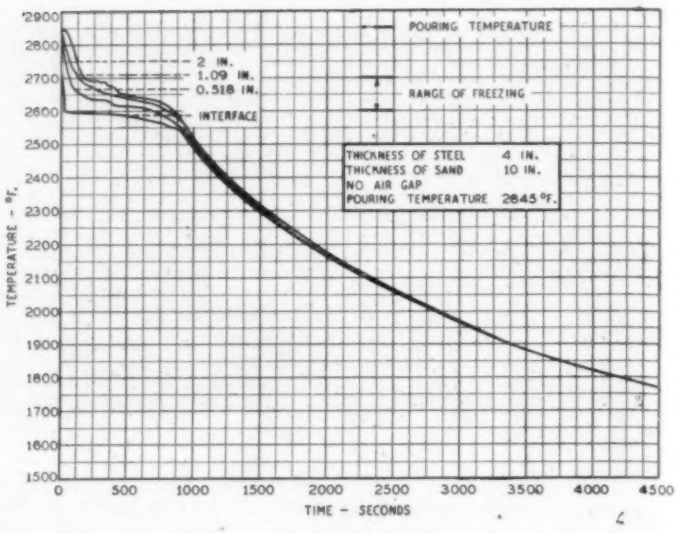


Fig. 7 (Left)—Temperatures in 2-in. slab casting at various times and distances at and from mold-metal interface. Fig. 8 (Right)—Same as Fig. 7 for 4-in. slab.

(abscissa) axis. Then, relatively slowly, the temperature drops and the heat of fusion of outside layers is spent. Simultaneously the properties change (from "liquid" to "solid" values): the change occurs in nature gradually and continuously, but was represented in the experiments in one step.

The change is toward lower specific heat, and toward higher thermal conductivity. Both changes exert influence in the same direction, namely, toward more rapid heat flow. The cooling of the inner layers is thus accelerated, and this accounts for the upward bend in the solidification curve, making the freezing toward the end very rapid.

Comparison of Chill and Sand Temperatures. In Fig. 17, chill temperatures found by direct experiments are plotted together with chill temperatures found from the electrical experiments. It has been stated previously that the direct experiments for this case were made at an earlier date and with but slightly different conditions. The chill was 3½ in. thick instead of 3 in., and the pouring temperature was 2900° F. instead of 2845° F.

The curves, if taken for the present conditions, therefore, should be somewhat lower; this would bring the curves for 1.5 in. from the steel-chill interface closer together but would slightly separate the curves referring to a point 3 in. from the interface. In view of the many difficulties in such experiments, the coincidence of the curves can be called excellent. This was taken as additional justification for the selection of the air gap times as explained in the foregoing.

The sand temperatures are compared for experiment S_2 and shown in Fig. 13. It will be found that the temperatures observed in the direct experiments are considerably lower than those measured by the electric analogy method. However, curves plotting temperatures against location at constant time, as used in Fig. 20, give a more favorable impression. One possible explanation for the discrepancies would be the way of placing the thermocouples in the sand. In drying, the sand can shrink away from the thermocouple and thus cause insulation of the couple with resulting lower indicated temperatures*.

A further explanation could be wrong selection of sand properties in the electric experiments. In view of the good check of freezing times, this is not very probable. As can be seen from Fig. 13, the air gap does not have sufficient influence on sand temperatures to make a possible air gap a plausible explanation for the discrepancies.

Temperatures in Slab Castings. In the experiments so far, there was no possibility of comparing steel temperatures within the castings themselves by direct and electric experiments because no quartz tubes were obtainable for protecting the thermocouples for measuring these

*Personal communication by C. B. Bradley, Johns Manville Research Laboratory, Manville, N. J.

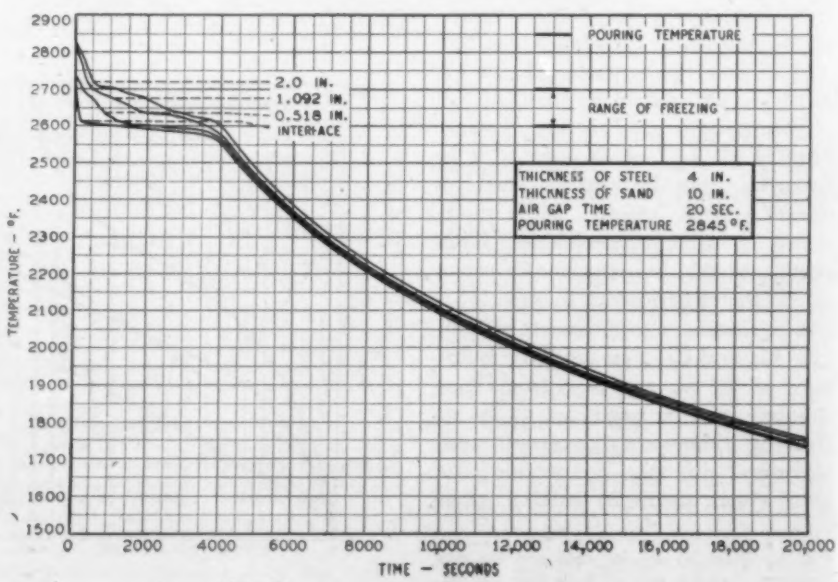
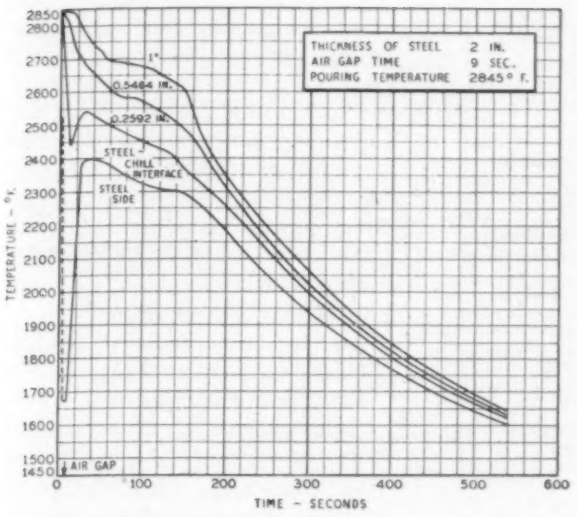


Fig. 9—Same as Fig. 7 with 20 sec. air gap time.



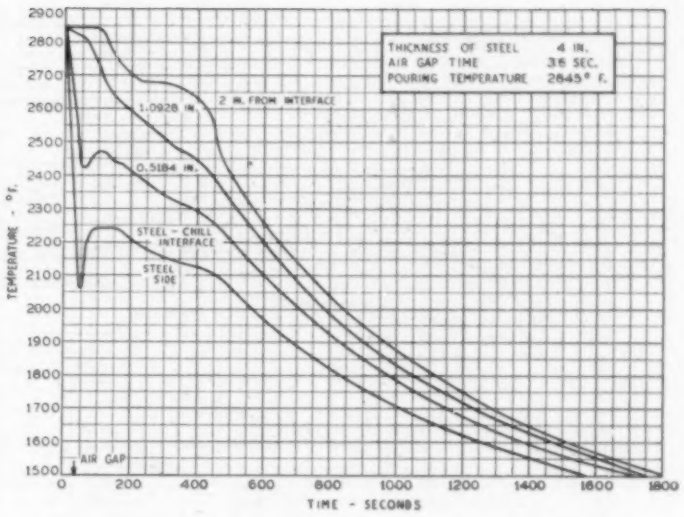


Fig. 10 (Left)—Same as Fig. 7 with 9 sec. air gap time. Fig. 11 (Right)—Same as Fig. 7 for 4-in. slab casting with 36 sec. air gap time and chill.

temperatures. However, the study of Figs. 7 to 12 reveals some very interesting facts.

Except for the very early times, temperature differences in the casting are small. The term "very early" must be used in a relative sense. For the 2-in. casting (Fig. 7), the temperatures at various points come close together after approximately 900 sec. The same holds true for the 4-in. casting with no air gap (Fig. 8), whereas for the 4-in. steel with air gap (Fig. 9), the curves more nearly coincide only after approximately 4000 sec.

The temperatures in the steel when cast against the chill lie somewhat farther apart, but after the initial period, the length of which again depends on the thickness of the steel, the differences are still not large.

This may, in part, account for the opinion† that the constitution diagrams as published do not hold for commercial foundry practice. The temperature differences between points near the surface and the center of the casting, particularly in sand molds, are so small that they lie almost within the accuracy of the measuring devices available in industrial foundry laboratories.

Comparing Figs. 8 and 9, it can be seen that the temperatures in the casting with and without air gap are appreciably different at any given time. Take, for example, a time 2000 sec. after pouring. With no air gap, the temperature is approximately 2170° F., whereas with 20 sec. air gap, the temperatures in the casting are 2670 and 2590° F.

Thus the time of formation of the air gap can be checked by measuring the temperature in the casting at a given location. The differences in these temperatures with air gap and with no air gap are so large that they can be measured with fair accuracy and thus a check on the assumption of "no air gap" in sand casting can be obtained.

In casting against chills, the differences are not so marked, but curves, which were taken on the heat and mass flow analyzer and were not included in this report, tend to indicate that, for casting against chills, this method of ascertaining the air gap time is also promising.

Heat Balance Between Steel and Sand. The experiments can be

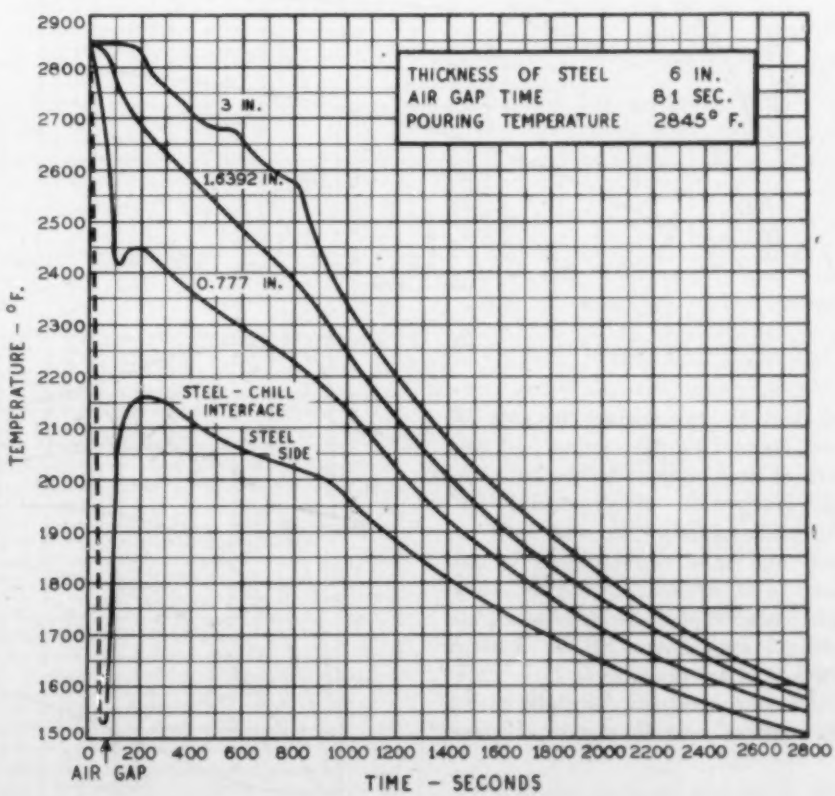


Fig. 12—Same as Fig. 7 for 6-in. slab casting with 81 sec. air gap time and chill.

†Personal communication by C. W. Briggs, Steel Founders' Society of America, Cleveland.

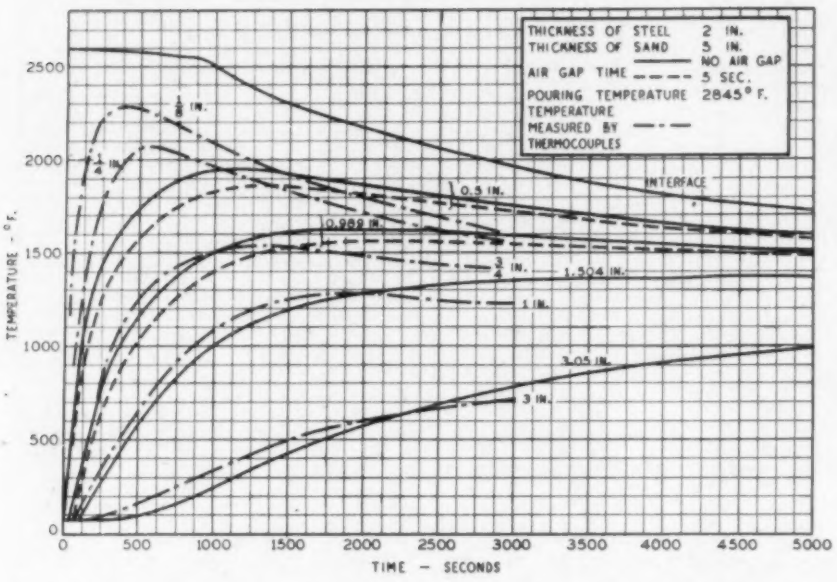


Fig. 13—Temperatures in sand for 2-in. slab casting at various distances and different times with no and 5 sec. air gap times for heat flow analyzer data. Superimposed are the temperatures measured by direct experiment[5].

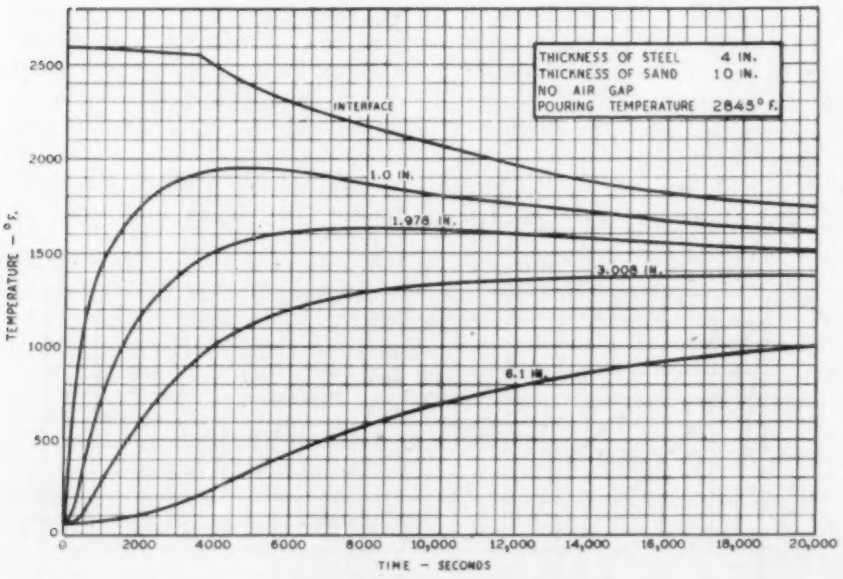


Fig. 14—Same as Fig. 13 for 4-in. slab casting.

checked by calculating the loss of heat content of the casting and the gain of heat content in the sand for any given time after pouring (in the chill experiments, the gain of *chill and sand* heat content would have to be calculated). A tentative heat balance of this kind was set up for the experiment S_2 for a time 100 sec. after pouring.

The temperature distributions in the casting and in the sand were drawn by plotting the temperature distance relation at constant time (100 sec.) from the curves shown in Figs. 7 and 13, respectively. These curves are shown in Fig. 20. The curve for sand is shown for the electric experiment as well as for the direct experiment.

The heat balance yields the following values:

Loss of heat content of the steel, by electric analogy..2163 Btu.
Gain of heat content of the sand, electric analogy experiment .....2410 Btu.
Direct experiment .....1840 Btu.

In considering these figures, it should be kept in mind that, for the constant time curves, relatively few points are available and that a minor change in interpolation can yield considerably different answers. The heat gain curves for direct and electric analogy experiments appear reasonably close and yet result in a heat gain 30 per cent apart. The calculations for loss and gain of heat content are shown in detail in Appendix 2. In view of the difficulties in interpolation, the check appears to be satisfactory.

Conclusions

The electric analogy method appears to be a promising tool, provided that the necessary thermal properties are known and the problem of air gap occurrence can be solved. There is reason to believe that it will be able to yield the answers to the various problems of solidification confronting the foundrymen.

It appears to be possible to establish with reasonable approximation

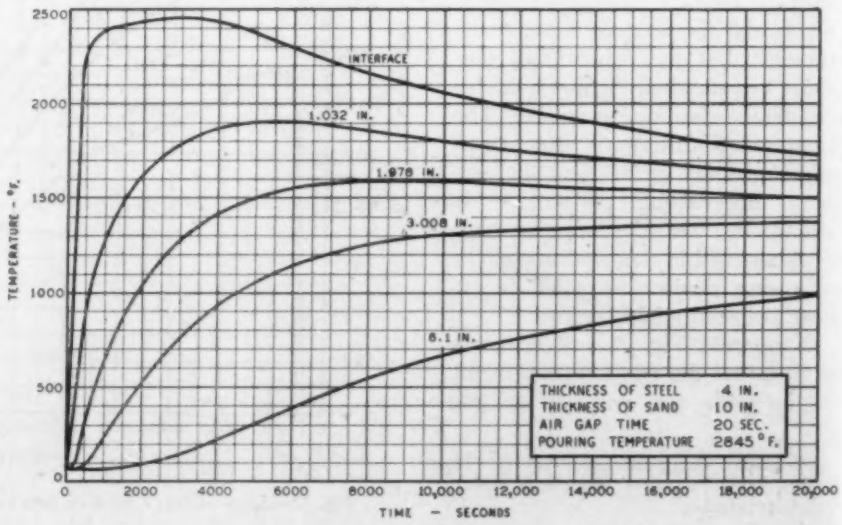
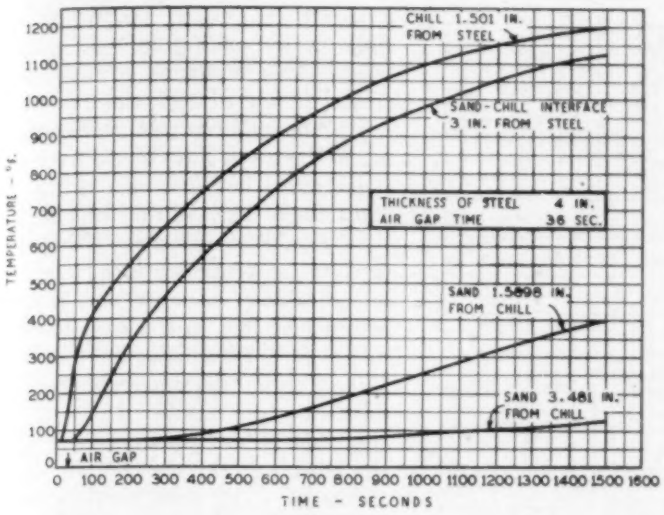


Fig. 15—Same as Fig. 13 for 4-in. slab casting with 20 sec. air gap time.


CHILL 1.501 IN. FROM STEEL
SAND-CHILL INTERFACE 3 IN. FROM STEEL
THICKNESS OF STEEL 4 IN.
AIR GAP TIME 38 SEC.
SAND 1.5898 IN. FROM CHILL
SAND 3.481 IN. FROM CHILL
AIR GAP
TEMPERATURE - °F.
TIME - SECONDS

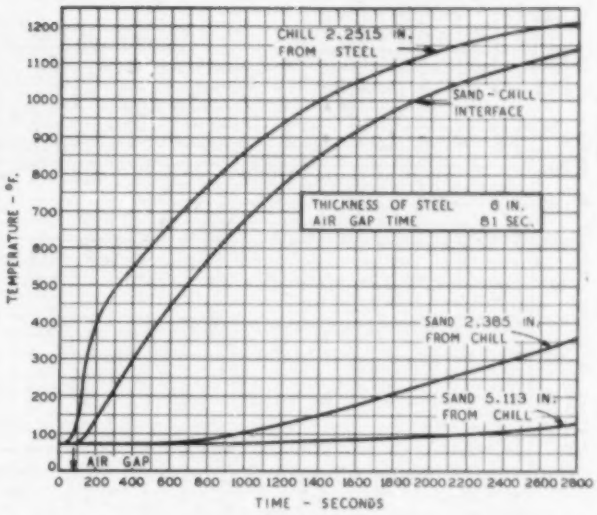


Fig. 17 (Left)—Same as Fig. 16 for 4-in. slab casting with 36 sec. air gap time. Fig. 18 (Right)—Same as Fig. 16 for 6-in. slab casting with 81 sec. air gap time.

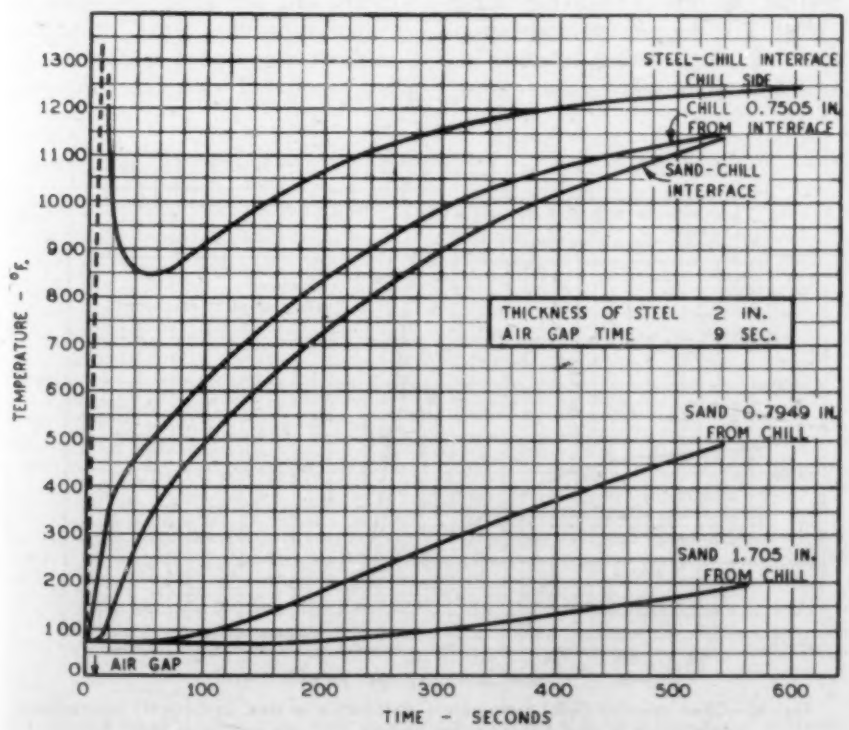
one curve for sand casting and one for chill casting showing the freezing times as functions of thickness independent of total thickness of the casting. This approximation holds better for small thicknesses than for large thicknesses and becomes progressively poorer as the thickness increases.

Complete solidification for any one casting branches off from the general curve. Figure 21 shows such general freezing curves. From this figure, it may be seen that an adequate chill speeds up complete solidification approximately in the ratio 1 to 25 at least for slabs up to 4-in. thick; the 2-in. slab freezes in 55 sec. with chill and in 140 sec. without chill; the 4-in. casting freezes completely in 190 sec. with chill and without chill in 540 sec.

The time of formation of air gap is of major influence in the case of chilled castings but of small influence in the case of sand castings. It is not readily understandable why this should be the case. The air gap may be caused by the difference between contraction of the casting and expansion of the mold. The contraction of the steel is, of course, faster in the case of chill castings, but on the other hand the expansion of the chill is probably larger than that of the sand. However, there is the possibility of the sand expanding because of the pressure of the air and other gas between sand particles*.

As mentioned in the introduction, this report is considered only as preliminary work and is intended primarily to investigate the possibility of using the electric analogy method. The author feels that this method is promising, but that, because of the uncertainty surrounding physical properties, further correlating experiments are desirable.

Fig. 16—Temperatures in chill and sand for 2-in. slab casting with 9 sec. air gap time.



Acknowledgments

The author is indebted to the other members of the Heat Transfer Committee, particularly to H. F. Taylor, K. L. Clark, and E. C. Troy, who gave freely of their time in planning the experiments and discussing the results. Further thanks are due to M. P. Heisler and Miss M. Snyder, Columbia University, who carried out the major part of the experiments.

Appendix I

Modifications of Electrical Analogy Method When Applied to Casting Freezing Problems

The basis of the electric analogy method has been published repeatedly[3]. It will be assumed here that the reader is familiar with the method. For studying the freezing

*Personal communication by P. E. Landolt and C. R. Wiggins.

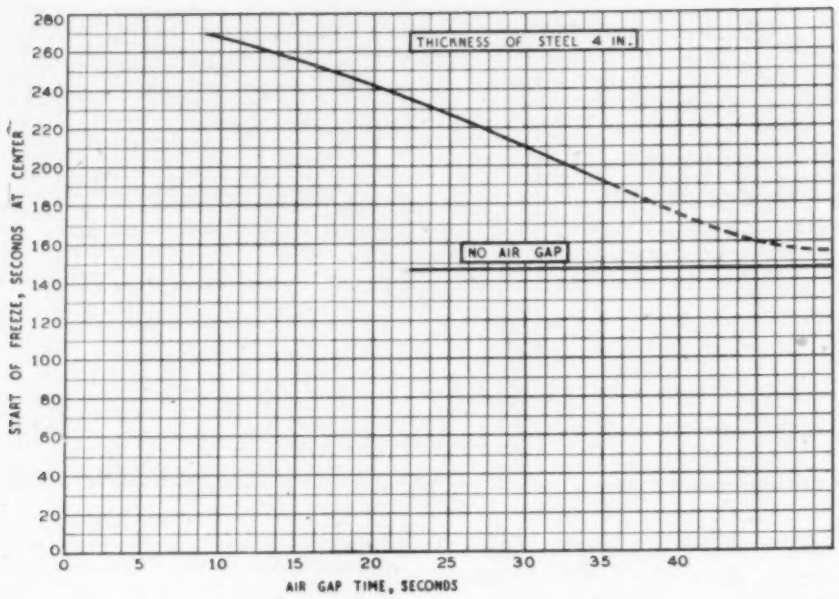


Fig. 19—Influence of air gap time on freezing time of center of 4-in. slab casting using chill.

of castings, however, several modifications of the simple basic procedure were necessary.

The heat of fusion, the change of properties between liquid and solid steel, and the necessity of measuring with fair accuracy a limited voltage (temperature) range at high voltage (temperature) level offered special difficulties.

The heat of fusion, which is liberated over a certain freezing range, acts as a temporary increase in specific heat and was so represented. To facilitate the necessary changes in the circuit, special switch frames were built.

The procedure of the freezing experiments is as follows:

a. Build an electric circuit representing the casting.

b. Build electric circuit representing chill and/or mold.

c. Provide for electric capacitors to represent the apparent increased specific heat (heat of fusion).

d. Load the circuit representing the casting to a voltage (temperature) corresponding to the pouring temperature.

e. Load the heat of fusion capacitors to the voltage (temperature) corresponding to the upper end of the freezing range (2700° F.).

f. Connect the "casting circuit" to the "chill-mold circuit" or the "mold circuit" (*C*-experiments and *S*-experiments, respectively).

g. Observe the voltage drop in the "casting circuit" and the voltage increase in the "chill-mold circuit" or "mold circuit."

h. As soon as the voltage at any point in the casting circuit has dropped from the value corresponding to the casting temperature to that corresponding to the upper limit of the freezing range, the heat of fusion capacitor is inserted at this point of the circuit.

i. The rate of temperature drop at this point now will be slower but will continue. When the voltage has reached a value equivalent to the middle of the freezing range (2650° F.), the resistors and capacitors of the casting circuit are switched from the values corresponding to liquid properties to those corresponding to solid properties. This results in a slight increase in rate of temperature drop.

j. When the voltage corresponding to the lower limit of the freezing range is reached, the heat of fusion capacitor is taken out of the circuit.

It should be understood that all three steps mentioned in *h*, *i*, and *j* do not always occur in one section before first step in the next section starts. If, for example, the sections, starting from the interface toward the center, are numbered by 1, 2, 3, etc., and if the three changes are characterized by the letters used above (*h*, *i*, *j*), then the following is a typical record of an experiment S_4: 1*h*; 1*i*; 2*h*; 3*h*; 4*h*; 2*i*; 5*h*; 6*h*; 3*i*; 7*h*; 8*h*; 9*h*; 10*h*; 4*i*; 5*i*; 6*i*; 1*j*; 7*i*; 8*i*; 2*j*; 9*i*; 10*i*; 3*j*; 4*j*; 5*j*; 6*j*; 7*j*; 8*j*; 9*j*; 10*j*.

The points 1 to 10 were at the following distance, in inches, from the steel-sand interface: 0.0740, 0.2222, 0.3704, 0.5184, 0.6926, 0.8926, 1.0926, 1.3540, 1.6770 and 2.000.

After completion of the experiments, the electrical terms are translated into heat terms.

It has been mentioned previously that the accurate measurement of small voltage changes at a high level offered additional difficulties. These difficulties are similar to those encountered in temperature measurements and are there overcome by "suppressing the zero." A similar method was applied in the electric experiments. Instead of measuring

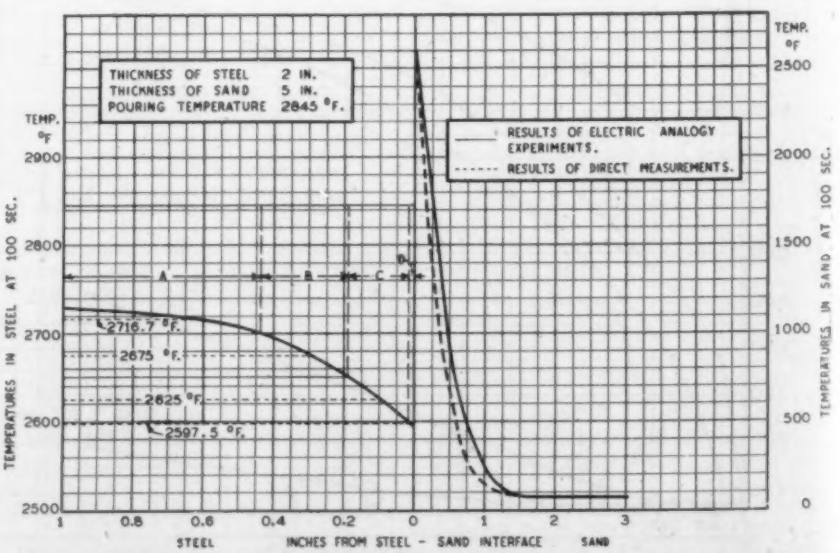


Fig. 20—Chart showing (left) temperature distribution in steel and (right) temperature distribution in sand 100 sec. after pouring 2-in. slab casting at 2845° F.

the voltage difference between any given point and zero, an auxiliary voltage was introduced. The temperature difference between the point in question and the auxiliary voltage was determined. This method proved to be entirely satisfactory.

Thermal Values Used in Experiments. The electric experiments are based on a knowledge of the thermal properties of the materials. Therefore, it is proper to give the values used in the experiments and justify their selection.

Thermal Conductivity of the Steel. Selected Values: solid, 18.4 Btu./ft./hr./° F.; *liquid,* 9.2 Btu./ft./hr./° F. The National Bureau of Standards gives a value of 0.076 cal./cm./sec./° C., which corresponds to 18.4 Btu./ft./hr./° F. This figure checks with the values shown in the "Second Report of the Alloy Steel Research Committee of the (British) Iron and Steel Institute"[9] and it was indicated that all steels seem to have conductivities between 0.06 and 0.08 cal./cm./sec./° C., at a temperature between 700 and 900° C. Lacking more accurate data, the value given in reference 8 was selected.

No value for conductivity of liquid steel can be found in literature. J. B. Austin (personal communication) advises that based on study of all available data, a conductivity of one-half the value of solid steel, namely 9.2 Btu./ft./hr./° F., appears reasonable.

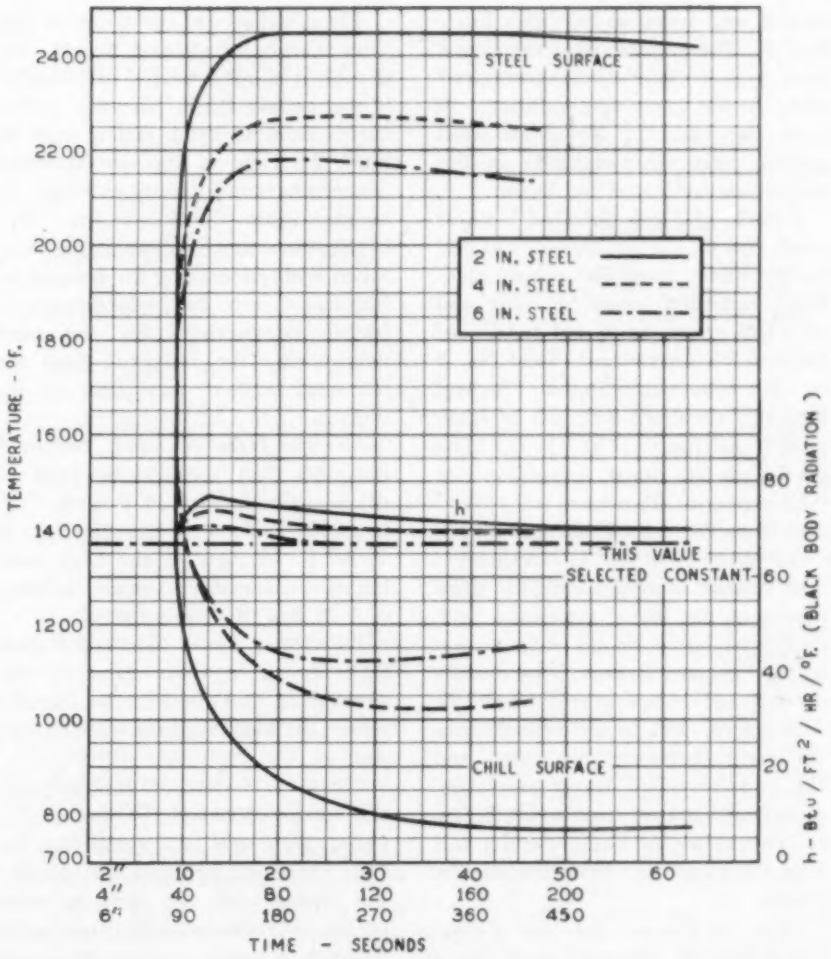


Fig. 22—Temperature of steel and chill facing air gap in various size slab castings. Also shown is *h*, air gap conductance (by radiation) at respective steel and chill face temperatures.

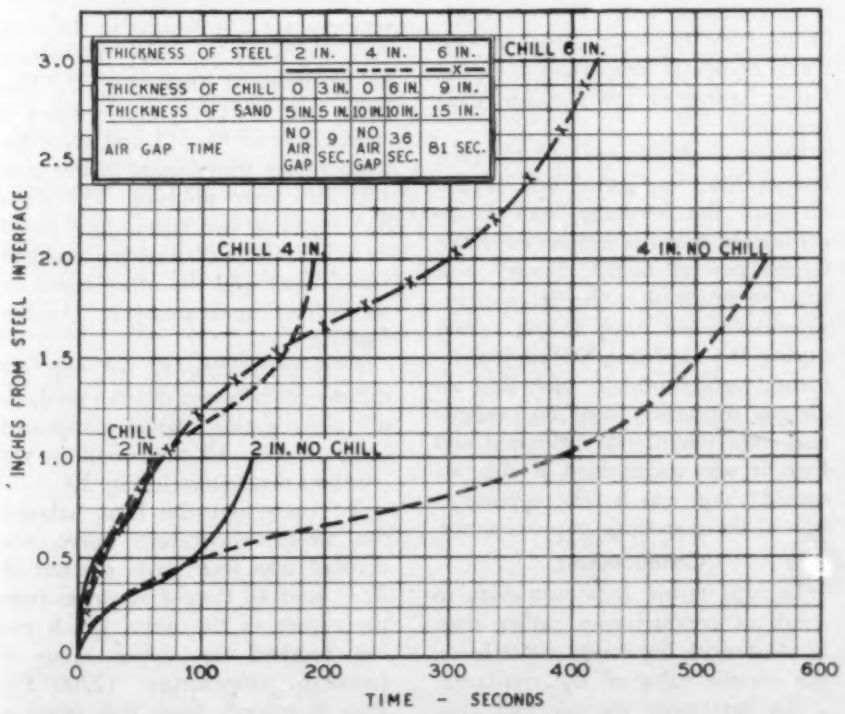

THICKNESS OF STEEL 2 IN. 4 IN. 6 IN.
THICKNESS OF CHILL 0 3 IN. 0 6 IN. 9 IN.
THICKNESS OF SAND 5 IN. 5 IN. 10 IN. 10 IN. 15 IN.
AIR GAP TIME NO AIR GAP 9 SEC. NO AIR GAP 36 SEC. 81 SEC.
CHILL 6 IN.
CHILL 4 IN.
4 IN. NO CHILL
CHILL 2 IN.
2 IN. NO CHILL
INCHES FROM STEEL INTERFACE
3.0
2.5
2.0
1.5
1.0
0.5
0
0 100 200 300 400 500 600
TIME - SECONDS

Fig. 21—Effect of chill and no chill on rates of freezing of various thicknesses of steel.

Specific Heat of Steel. Selected Values: solid,* 0.165 Btu./lb./° F.; *liquid,* 0.200 Btu./lb./° F. Austin (personal communication) recommended 0.144 cal./gram/° C., for solid steel and 0.180 for liquid steel. From Table 45 in the previously-mentioned "Second Report"[9], it appears that the mean specific heat between various temperatures and 50° C. drops from 0.168 cal./gram/° C., at 850° C. to 0.1156 at 100° C. However, between 850 and 750° C., there is but little change. Values drop from 0.168 to 0.163 cal./gram/° C. Umino[10] quotes similar values.

Inasmuch as it is not expected that the temperature at any point in the steel would drop during the solidification period to values below 700° C. (1292° F.), the value, from refer-

*One Btu./lb./° F. (mean) = one gram-cal. /gram/°C.

ence 9, was taken to be 0.165 Btu./lb./° F. The specific heat for liquid steel was increased, as compared with Austin's recommendation, to keep the ratio of liquid to solid specific heat approximately in the magnitude indicated by Austin.

Density of Steel. Selected Values: solid, 468 lb./cu. ft.; *liquid,* 450 lb./cu. ft. Austin (personal communication) suggested values for solid steel of 7.483 grams/cm.^{3} and for liquid steel of 7.2 grams/cm^3. Steel No. 3 in the above-mentioned "Second Report"[9] mentions a density of 7,859 grams/cm^3 for steel at 15° C. The coefficient of linear expansion for 0.22 per cent carbon steel is 0.1316×10^{-4} from 20 to 1000° C. and 0.1248×10^{-4} from 20 to 900° C. (Driesen[11]). The volume increases with the third power of the linear expansion and, therefore, based on the information in the "Second Report," the density at elevated temperatures would be 7.56 grams/cm^3. In the experiments, the mean between this value and the value given by Austin was taken, namely 7.5 grams /cm^3=468 lb./cu. ft. The value for liquid density was kept unchanged as recommended by Austin.

Heat of Fusion. Selected Value: 126.2 Btu./lb. Powell[12] indicates a value of 3900 cal./gram mol. This corresponds to the selected value given above.

Freezing Range. Selected Value: 2700-2600° F. These values have been taken from the constitution diagram.

Pouring Temperature. Agreed upon before start of the experiments: 2845° F. For the chill, the "solid properties" of the casting were taken. The sand properties appear surprisingly hard to find in literature. It would appear that determination should not offer major difficulties.

Conductivity of Sand. Selected Value: 0.9 Btu./ft./hr./° F. Chworinoff[6] mentions a conductivity of 0.65 Btu./ft./hr./° F. for sand having a density 15 per cent higher than the use used in the present experiments. Reducing the density to the values used here would lead to still lower conductivity because, in general, the conductivity decreases with the density. Norton[13] shows three curves of conductivities for silica. The conductivity values vary from 0.6 Btu./ft./hr./° F. (for 400° F.) to 1.3 (for 2400° F. temperature).

These values are the mean of the three curves mentioned before. Although it is not so stated specifically, it was believed that Norton's recent curves refer to brick rather than to sand. In view of the uncertainties concerning conductivity of sand, an average value (0.9 Btu./ft./hr./° F.) of Norton's most recent figures was taken without making an attempt to introduce into the experiments a higher conductivity for the sand neighboring the interface than for the sand farther away from the interface.

Specific Heat of Sand. Norton[13] indicates that the specific heat of silica varies from 0.28 Btu./lb./° F. at 2200° F. to 0.23 Btu./lb./° F. at 1100° F. In view of the high temperature near the interface, a value of 0.28 Btu./lb. was selected.

Density of Sand. Selected Value: 93.6 lb./cu. ft. This value is the average of that used in the foundry where the bleeding tests were carried out.

Air Gap Resistance. Undoubtedly the air gap occurring in the solidification of metals is so small that the heat exchange between the solidifying metal and the chill or sand occurs by radiation only, because in a space so small, no convection can occur. Since the casting is surrounded on all sides by the cooling material, it probably is permissible to consider the radiation as black body radiation only. The exchange of heat by radiation between two black bodies is proportional to the fourth power of the absolute temperature.

Because of change of the face temperatures on either side of the air gap, the possibility had to be considered that the difference of the fourth powers might change with time so much that the air gap resistance would have to be varied during the experiment. The experimental procedure was such that an air gap resistance based on preliminary experiments was estimated and then it was ascertained if this assumed value was a fair representation of the actual air gap resistance.

Conductances

In heat terms, it is customary to speak of conductances rather than of resistances, the conductance being the inverse value of the resistance.

To determine the air gap conductance, temperature charts were determined for the temperatures of both air gap faces. These temperatures, for experiments C_2, C_4, and C_6, are plotted against time in Fig. 22. The curves do not start with zero time because the steel temperature drops very rapidly from 2845° F. to the starting value of the curves, whereas the chill surface increases from 70° F. to the same value.

Theoretically, if there is no contact resistance before the air gap becomes active, this decrease and increase occur in infinitely short time. For the air gap, only the temperatures starting from this point are of interest, and therefore only these are plotted in Fig. 22.

Based on these temperatures, the appropriate boundary conductances were determined by using the curves shown in Fig. 27 of McAdams' book[14] on heat transmission. These values are plotted as h in Fig. 22. Fortunately, h changes but little with time so that it is not necessary to change the air gap resistance during the experiment. Moreover for the three different steels, the values lie close together and therefore a uniform value of h=67.6 Btu./sq. ft./hr./ ° F., was selected.

Appendix 2

HEAT BALANCE BETWEEN STEEL AND SAND (EXPERIMENT S_2)

The left half of Fig. 20 shows the temperature distribution in the steel 100 sec. after pouring, the values being obtained from Fig. 7. The right half of the picture shows a cross curve of Fig. 13 and gives the temperature distribution in the sand 100 sec. after pouring. The right half contains two curves, one based on the electric analogy method (solid line) and the other based on the direct measurements (broken line).

It is interesting to see that the differences between the two methods of investigation which appeared large in Fig. 13 are small in the constant time curve in Fig. 20.

To carry out the heat balance, the steel temperature curve was divided into four parts marked *A, B, C,* and *D*. Part *A* stretches from the center to the point which just has reached the upper range of freezing temperature (2700° F.). Part *B* extends from this point to that which just has reached the

Table 11

Steps in Calculating Heat Content from Fig. 20

Part	*Step*		
A	1	$0.562\times\frac{1}{12}\times(2845-2716.7)\times450\times0.2=$	541.0
B	1	$0.248\times\frac{1}{12}\times(2845-2675)\times450\times0.2=$	316.3
	2	$0.248\times\frac{1}{12}\times(2700-2675)\times450\times\frac{126.1}{100}=$	294.8
C	1	$0.170\times\frac{1}{12}\times(2845-2650)\times450\times0.2=$	248.8
	2	$0.170\times\frac{1}{12}\times(2650-2625)\times468\times0.165=$	27.4
	3	$0.170\times\frac{1}{12}\times(2700-2625)\times450\times\frac{126.1}{100}=$	603.5
D	1	$0.02\times\frac{1}{12}\times(2845-2650)\times450\times0.2=$	29.3
	2	$0.02\times\frac{1}{12}\times(2650-2597.5)\times468\times0.165=$	6.8
	3	$0.02\times\frac{1}{12}\times(2700-2600)\times450\times\frac{126.1}{100}=$	94.7
		(Shown in the text as 2163 Btu.)	2162.8 Btu.

mean temperature of the freezing range (2650° F.) where the properties for "liquid" were changed to "solid."

The third part, *C*, goes from this point to where the steel just has reached the lower limit of solidification (2600° F.). The last part extends from this point to the interface. For each part, the mean temperature was established. The values are as follows: Part *A*, 2716.7° F.; Part *B*, 2675° F. Part *C*, 2625° F.; Part *D*, 2597.5° F.

For each part, the total temperature drop from the original 2845° F. to the mean values quoted above was divided into steps according to the various specific heat values prevailing in the different ranges.

Section *A* was entirely within the range of "liquid properties." Section *B* had to be treated in two steps, one for the specific heat which is entirely within the liquid range and one for the heat of fusion which is given off between 2700 and 2650° F.

Part *C* was treated in three steps, one from 2845 to 2650° F. (liquid properties), one from 2650 to 2625° F. (solid properties), and one from 2700 to 2625° F. (heat of fusion).

Part *D* was treated in three steps, the first reaching from 2845 to 2650° F. (liquid properties), and the next from 2650 to 2597.5° F. (solid properties), and the third from 2700 to 2600° F. (heat of fusion).

The procedure will be clearer from the tabulation (Table 11) showing how in each part and step the heat content has been calculated. In the multiplications, the first figure shows the thickness in inches of the part (*A*, *B*, etc.); the next figure ($\frac{1}{12}$)serves to change over to feet; in the brackets the temperature difference in ° F. is shown, which applies to the respective step. Then follows the density in lb./cu. ft. and the specific heat (0.2 Btu./lb./° F. for liquid steel; 0.165 Btu./lb./° F. for solid steel.

Heat of fusion is reduced to "specific heat" by dividing the heat of fusion, 126.1 Btu./lb., by the temperature difference, 100° F., over which the heat of fusion is given up.

The heat gain of the sand was determined by integrating the area under the temperature-space curve.

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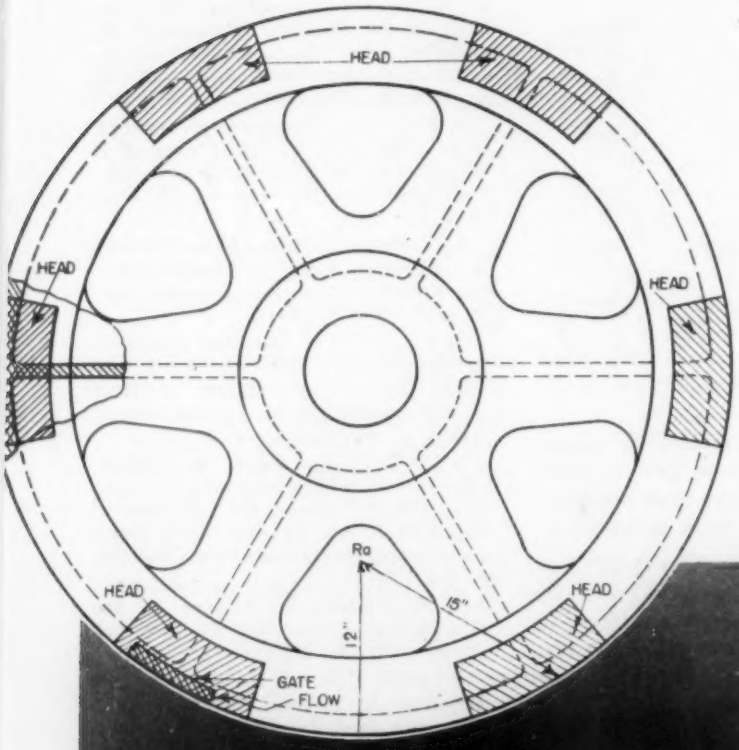
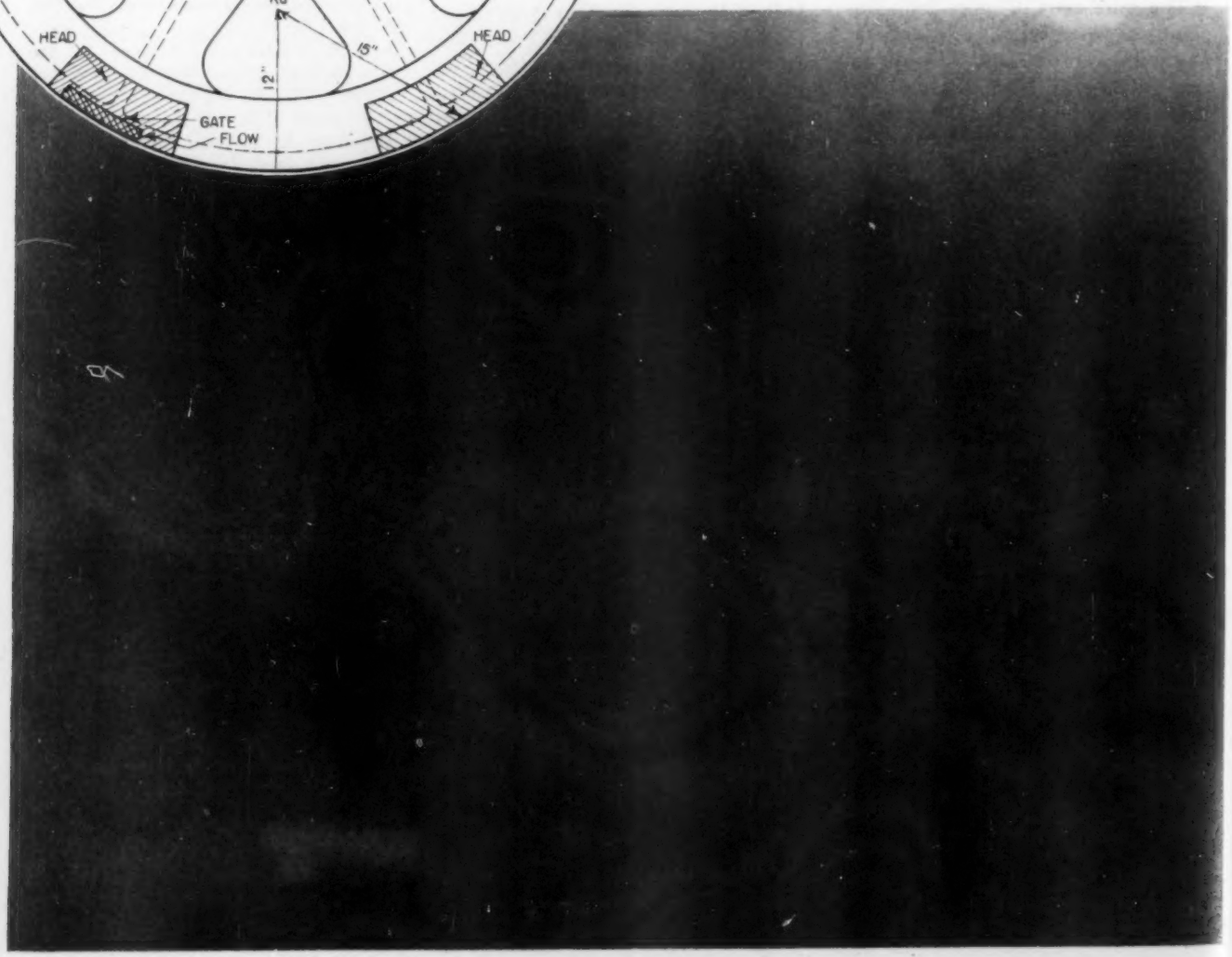
The Advantages and Limitations of GAMMA-RAY RADIOGRAPHY on SMALL STEEL CASTINGS

Fig. 1—Sketch showing conventional molding method for blank gear casting—open riser at each spoke junction and bottom gate. Fig. 2—Radiograph of rim section at a spoke junction shown in Fig. 1.



THE use of gamma-ray radiography as a tool for non-destructive testing in the small steel foundry is becoming more prevalent. It is a new process and has reached its present volume primarily because of war production demands. Previous to that time it had been viewed with fear and skepticism, even to the point where some producers refused to consider it.

A few foresighted foundry executives early recognized its possibilities and, when it became a necessity in the



• Improved methods of application and better understanding of interpretation standards have resulted in wide acceptance of radiography as an inspection tool and as a means of developing techniques to assure perfection of castings.

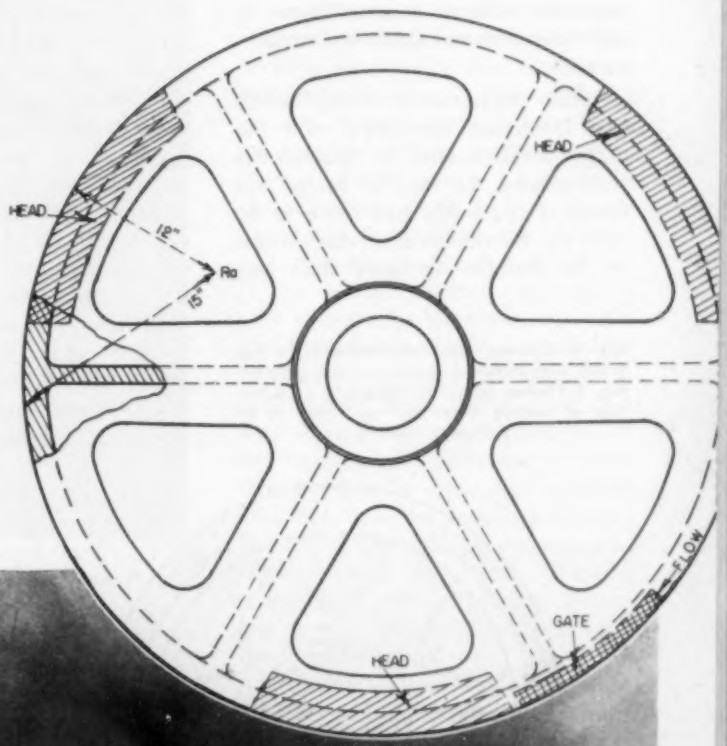
By R. H. Frank,
Chief Metallurgist, Bonney-Floyd Co.,
Columbus, Ohio

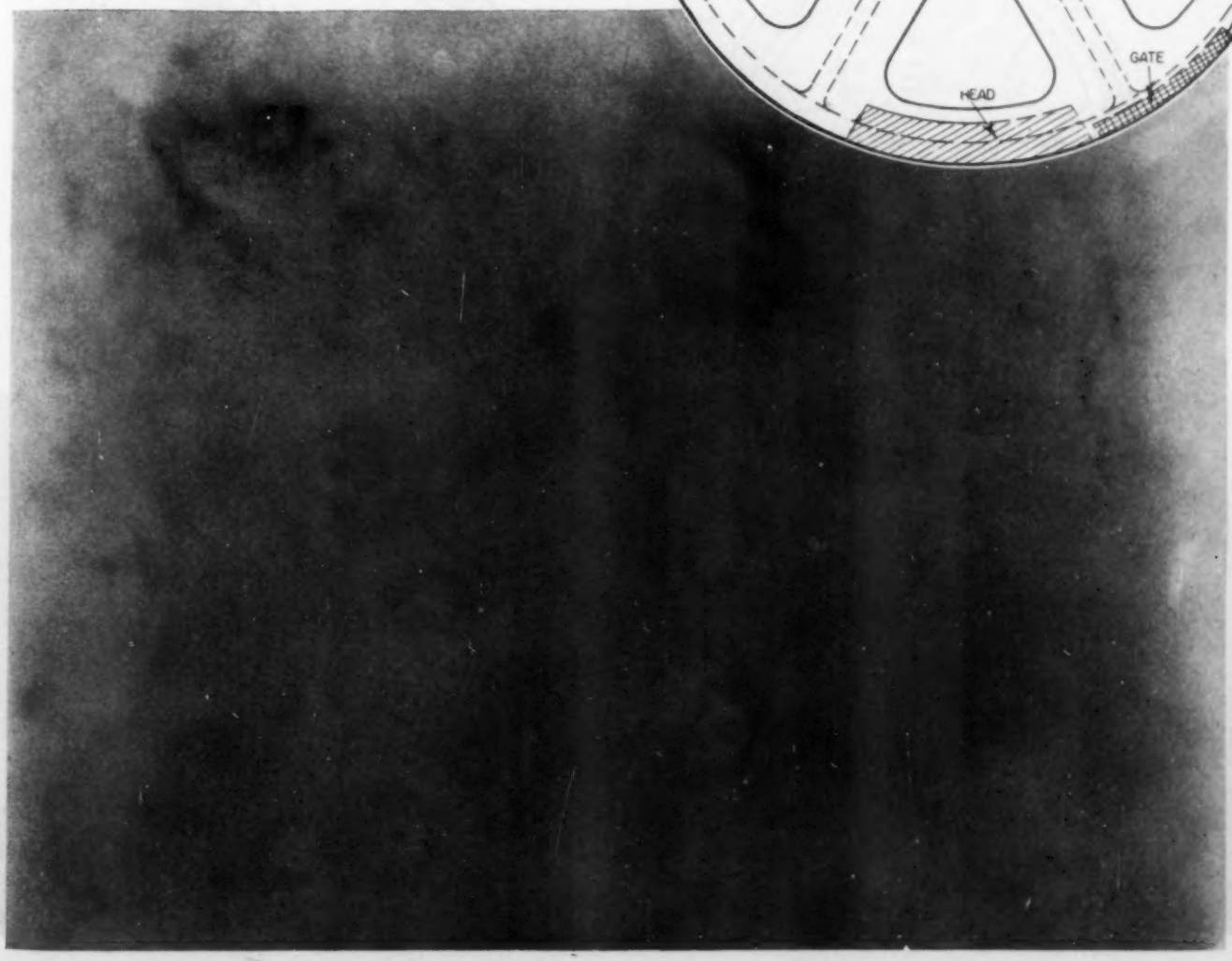
production of certain types of castings, were well paid for the knowledge their personnel had gained in previous years, not only from the standpoint of having experienced radiographers in their organization but also in its use and interpretations for foundry technique.

Slow acceptance of gamma-ray radiography in the industry is not altogether due to the foundries themselves. The promulgators of the process endeavored to introduce their technique too fast and in so doing, as is the American way when one is told he must do something, they received very little encouragement.

The main source of the objections, disregarding the cost, was in the interpretation of the shadow markings. Who was to say what a certain image on the film was

Fig. 3—Same casting shown in Fig. 1 but with three large risers placed between spokes. Fig. 4—Severe shrinkage shown in gate section of gear casting gated as shown in Fig. 3.





and what it meant, that is, as far as the serviceability of the castings was concerned? There were no standards for comparison and comparatively few persons who could intelligently interpret the images. Analogous to the early situation in radiography is the recent attempt to introduce magnetic particle testing into the foundries without a sound basis of interpretation and customer requirements.

While the names of Mehl, Barrett and Doan are associated with the early developments in gamma-ray radiography, the work of Briggs and Gezelius [1] probably had more to do with the introduction of this process in the foundry industry than any other. Their publication was the first discussion dealing entirely with steel castings.

Later in the same year these authors, in a private publication from the Naval Research Laboratory entitled "Instructions for Radiography with Radium," gave the industry its first working knowledge for the use of radium. Their basic instructions are still used, but in the intervening years many others have contributed improvements and advancements. Both the Army and Navy have issued radiographic standards for the inspection of steel castings, and the ASTM through Committee E7 has published "Tentative Methods of Radiographic Testing of Metal Castings" (E15-39T).

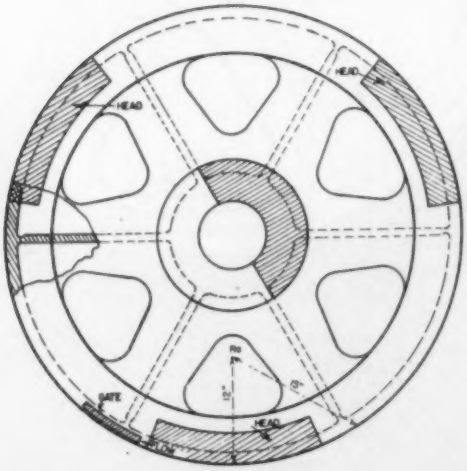
Radiography, like all other testing methods, is not foolproof; it has its limitations and no one can say that it is 100 per cent correct. However, if one is to achieve the best results it is necessary to be thoroughly acquainted with the technique, with strict adherence to details and interpretation.

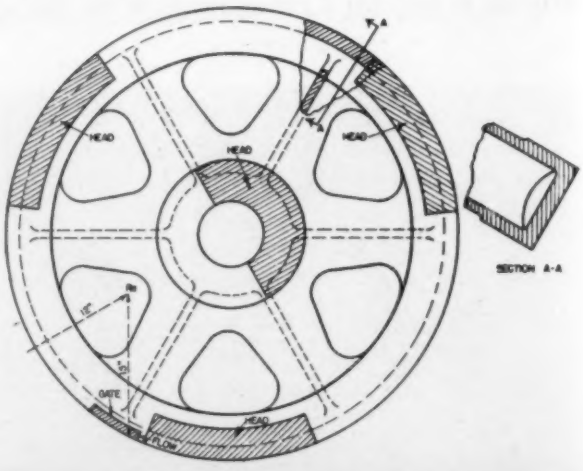
It is not within the scope of this discussion nor is it the intention to elucidate in detail the accepted technique for the making of gamma-ray radiographs. These requirements have been fully explained by Briggs and Gezelius,[1, 2, 6] Mehl,[3] Doan and Young,[4, 5] Woods,[7] Morrison and Nodwell,[8] Taylor,[9] Radium Chemical Co.,[10] and others.

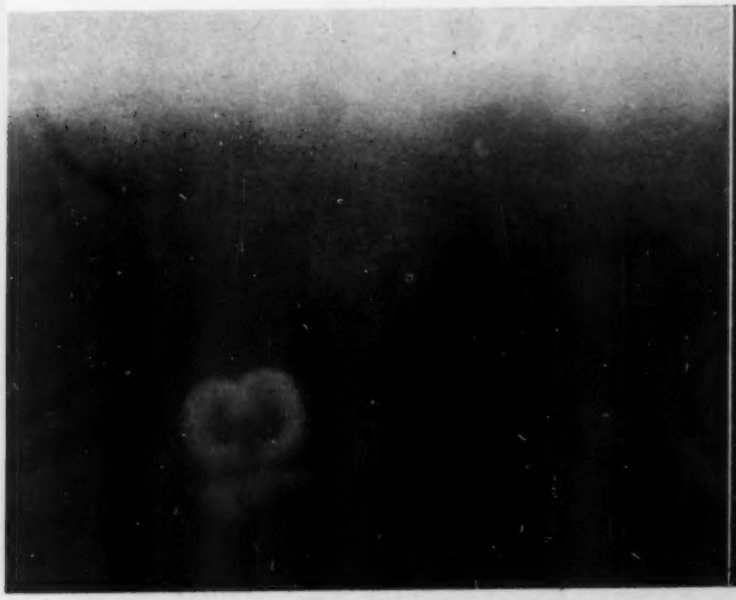
As previously mentioned, interpretation seems to be the main source of contention between consumer and producer inspectors, even by reference to a set of standards. This

Fig. 5—Casting with risers same as in Fig. 3 but with reduced section at rim junction. Fig. 6 (below left)—Shrinkage in gate section of casting shown in Fig. 5 due to insufficient feeding.

Fig. 7—Drawing of gear casting showing change in design to overcome shrinkage. Fig. 8 (below right)—Radiograph showing that shrinkage has been eliminated in rim section at former intersection (Fig. 7).







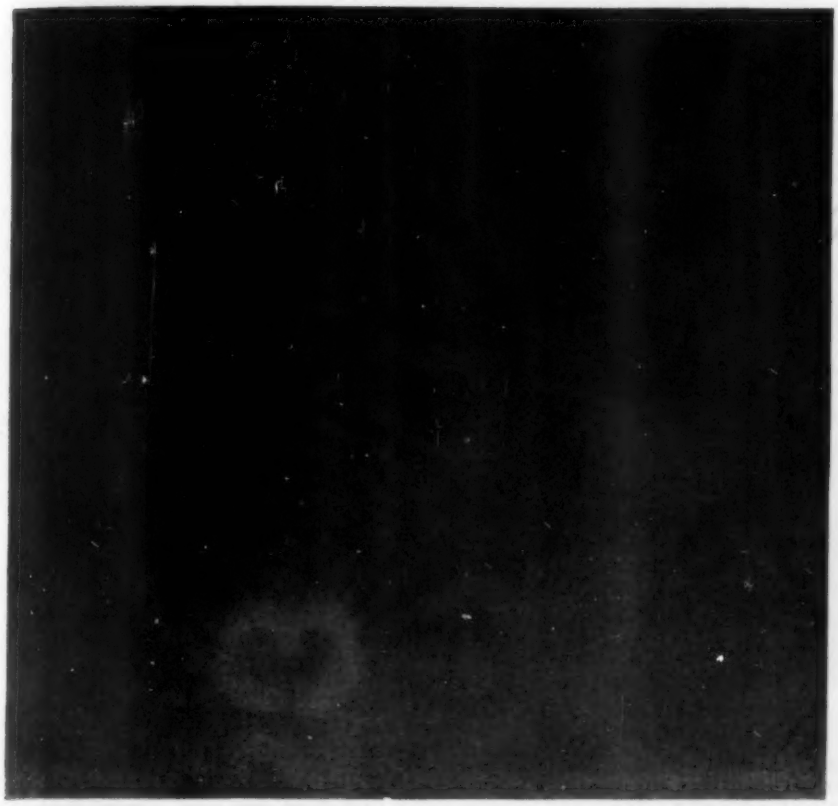


Fig. 9—Considerable shrinkage still present in gate section (see Figs. 7 and 8).

situation is natural and is to be expected, but it is doubtful if any serious disagreement would arise which could not be settled with satisfaction to both parties.

From the author's experience, most difficulties at the start arose within the shop personnel. Many times the skeptics had to be shown by dissecting the casting or carefully chipping the area, as shown on the film, so that the defect was revealed. However, it was not long before even the most doubtful were convinced of the value of radiography for the production of better castings.

At the present time there is a competitive situation between the foundry technicians, several inspectors and the cleaning room foreman as to which castings will be radiographed first, and sometimes it is necessary for the general manager to determine an order of preference.

Again, it is not the intention to enter into any discussion as to the relative merits of gamma-ray versus x-ray radiography. Both have their place in the industry and are more or less interchangeable. Radium is portable, economical, requires no elaborate machinery, lends itself to batch operation, requires less shielding and has more latitude.

On the other hand, x-rays are much faster and more sensitive, especially in the thinner sections. While the foundry in the future may use both sources, it is believed that radium will continue to be the most popular, except in those cases where it would be possible to use fluoroscopic methods, in which field the x-ray, at the present time, is the only means of supplying the energy.

Originally, radiography was developed as an inspection tool for the ultimate consumer to determine hidden flaws or defects in order to preclude the possibility of service failures. In this way the necessary repairs or rejections could be accomplished before serious damage resulted.

While this is still the practice, many foundries have taken it upon themselves to use radiography as a means to develop technique whereby such defects are eliminated by the examination of pilot castings. It may be mentioned here that the Navy, upon request, will furnish radium to be used for this purpose on their own castings. The availability of a unit is limited to its need for final inspection and is subject to recall without advance notice.

The former method for finding these defects was to destroy the casting by cutting it into small sections and examining these pieces visually. On small castings this was not very difficult and fairly rapid, but there was still no assurance that the part was sound since, unless very thin sections were cut, a flaw could exist between cuts and not appear on the surface, thereby giving a false sense of security. While such flaws as shrinks usually can be suspected in certain areas, they do not always appear in that section due to careless operators or pouring technique.

The cutting of large castings is time consuming, laborious, expensive and a much less secure method than in the case of smaller castings. With radiography the casting does not necessarily have to be destroyed, if defects are found, since in most cases it is possible to repair the affected area and make the necessary changes in heading and gating for subsequent elimination of the defect. If speed is essential, radiographic inspection can even be accomplished before the risers are removed.

Probably the best way to illustrate the use of radiography as a nondestructive method for the development of foundry technique is to cite examples or case histories. The case of a large blank gear will be followed.

Gating and Risering

These blank gears were about 6 ft. in diameter with a 12-in. face. They were designed with six spokes and an open or window-type web, as shown in Fig. 1. The molding method was convential, that is, an open riser at each spoke junction and a bottom gate.

The six risers were considered as necessary due to the heavy metal section at the junction of the spokes with the rim. It is essential that these areas be solid because the bottom of the teeth is about 1 in. below the cast surface, and if there are any shrinkage cavities the teeth will be weakened. With this molding method no shrinkage troubles were encountered.

While the entire rim was radio-

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by Steel Division, A.F.A.

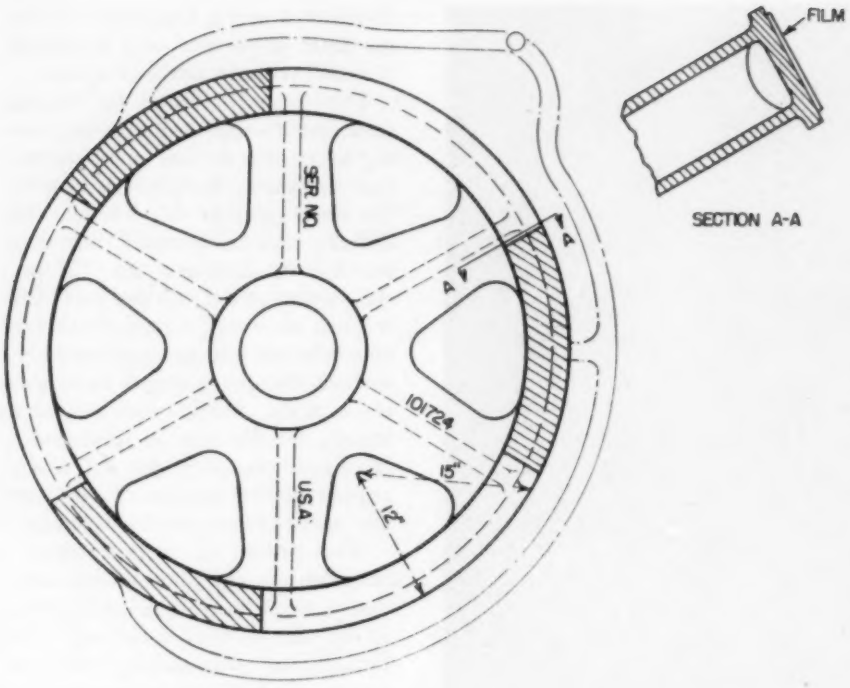


Fig. 10 (above)—View of gear casting showing change in gate position to eliminate shrinkage in gate section of rim. Fig. 11 (below)—Shrinkage in gate section has been overcome by change in gate position (Fig. 10).

graphed, it is not deemed necessary to display all of the films. In this and the following examples the internal structure of the junctions for each set is fairly constant, so one typical example should be sufficient for this purpose. Figure 2 shows one of these sections for this molding method.

In order to increase the yield, the idea was conceived that proper feeding of the spoke junctions could be achieved with three larger risers spaced between the spokes, as shown in Fig. 3, the theory being that one riser would feed two junctions. Radiographic inspection quickly disproved this assumption as severe shrinkage was found at the intersections (Fig. 4).

While this is the radiograph of the gate section and much more shrinkage is shown at the hot spot (top of film) created by the gate, it still is typical of the other intersections. There should be no question but that, considering the service of these gears, this casting is unsatisfactory and even the most lenient foundry-

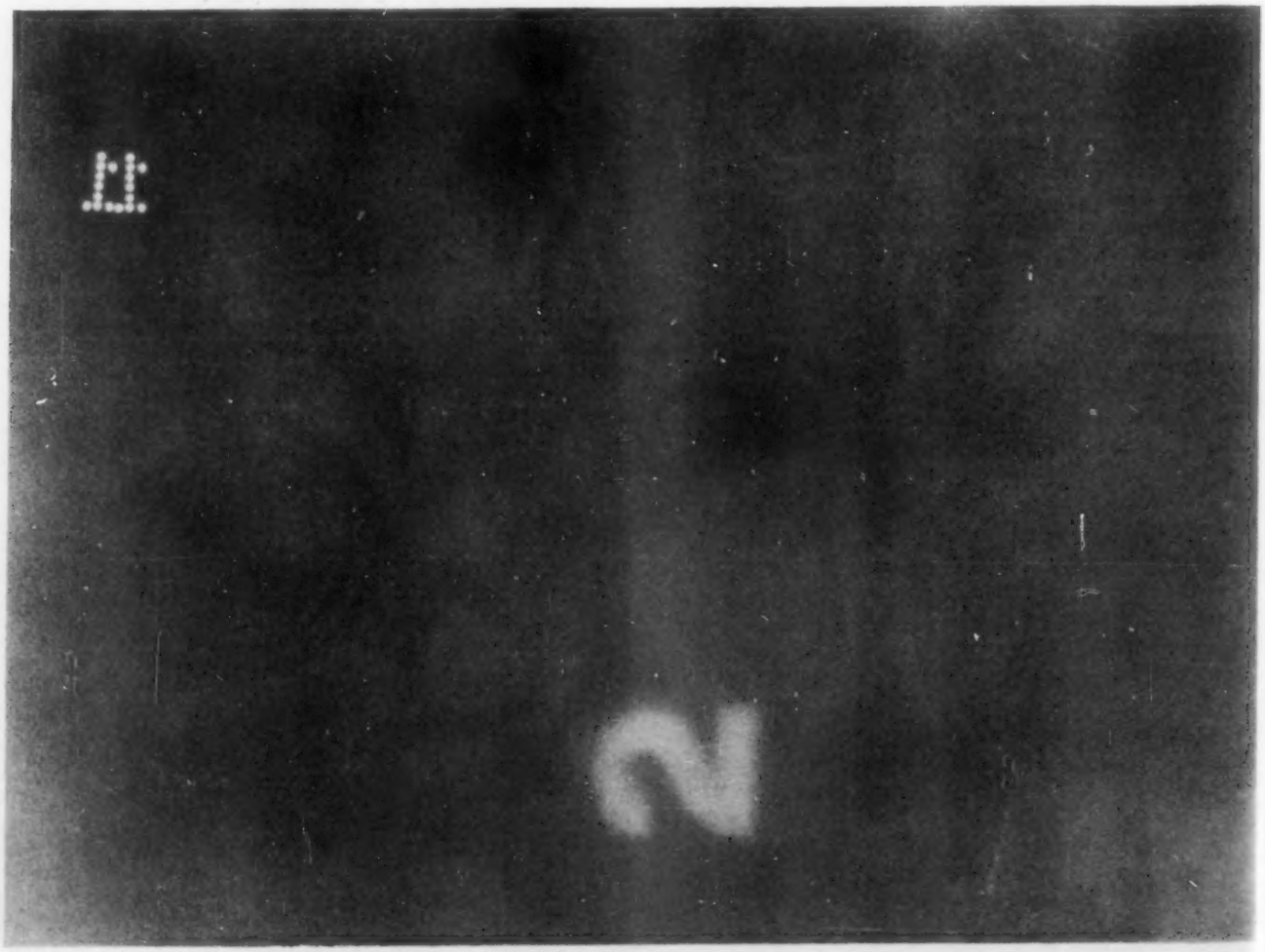


Fig. 12—Radiograph showing that "tight" plug fitted into wall section of casting was not satisfactory.

Fig. 13—Same section shown in Fig. 12 after plug had been removed and the hole welded.

man would quickly discard this molding method.

It is a well-known procedure among foundrymen that decreasing the metal section at the intersection of two or more ribs will lessen the propensity toward shrinkage in that area since it would be more uniform. Following along these fundamentals, it was suggested that the spokes be constructed at the rim junction, as shown in Fig. 5, and a casting was made according to this design.

Here again the films showed that this reduction in section was insufficient for these risers to properly feed the intersections. Severe shrinkage was found, as shown in Fig. 6. As in the previous example, this is the gate section and shows considerable shrinkage, for reasons explained, but is still symbolic. Needless to say, this method was quickly discarded because of the results obtained in this one casting.

Following along the same line of reasoning as before, the next design change was to divorce the intersections completely except, of course, at the web. In this manner the rim section was made as uniform as possible under the circumstances, as shown in Fig. 7. The radiographs showed (Fig. 8) that the rim at the former intersections was now solid, but that the gate section (Fig. 9) still contained a considerable amount of shrinkage.

Up to this point no one had ques-

Fig. 14—Shrinkage in large motor shell casting which had two large pole pieces on inside. No riser was used for feeding pole pieces inside of motor shell.

Fig. 15—Unfused chill in same section shown in Fig. 14.

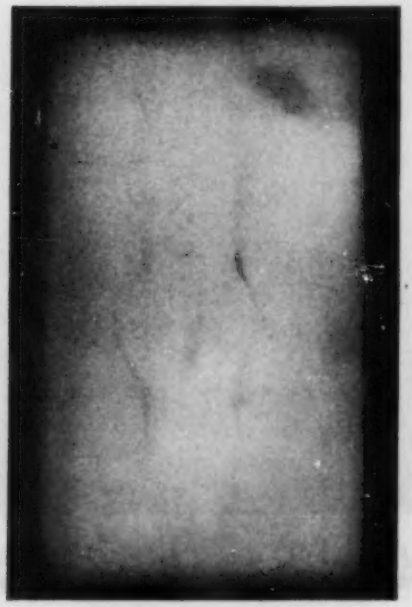


Fig. 16—Use of a pressure riser eliminated shrinkage (Figs. 14 and 15).

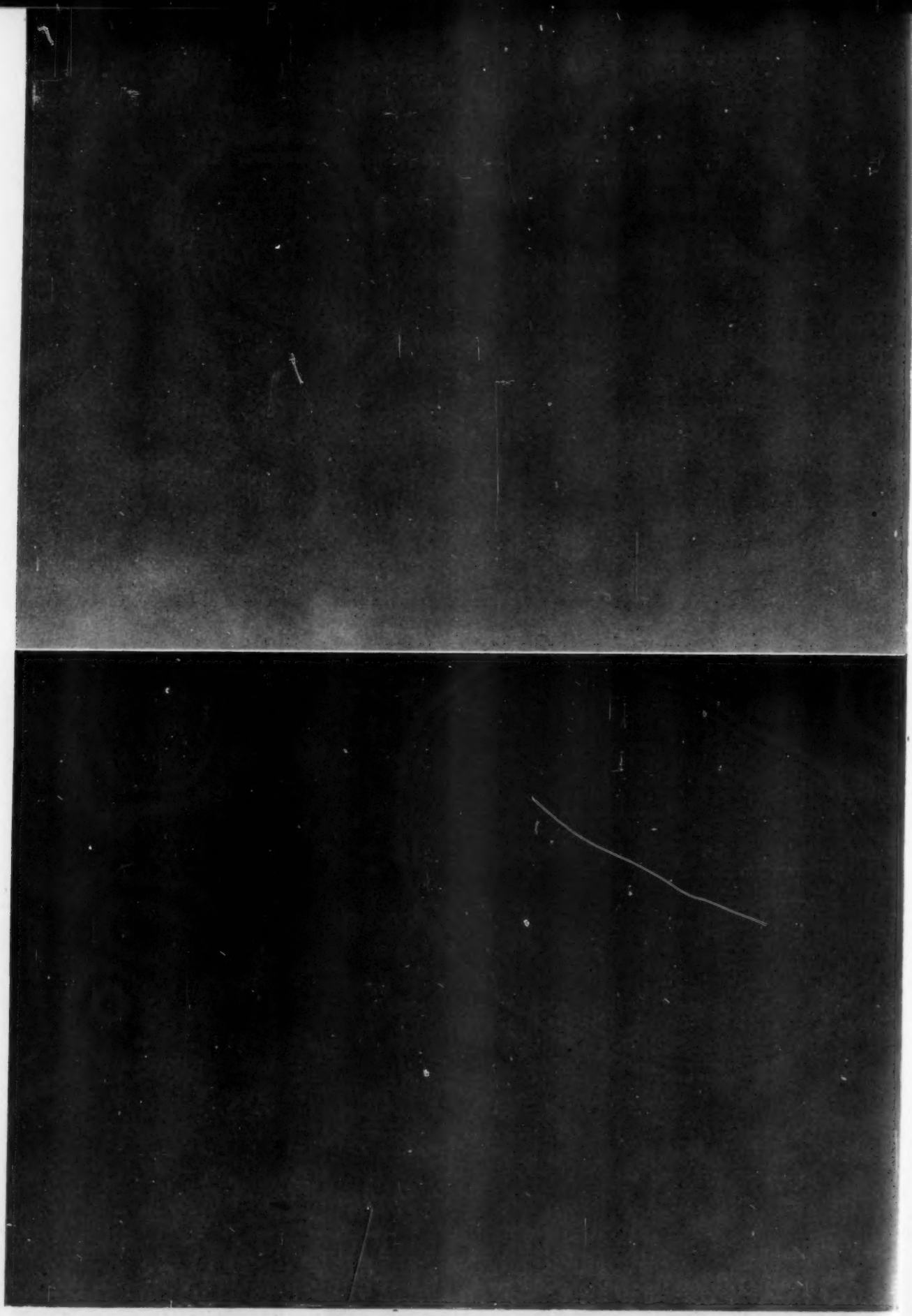


Fig. 17 (top)—Radiograph of ring casting section. No shrinkage present. Overall height, 12 in.
Fig. 18 (bottom)—Ring casting section, overall height, 11½ in. No shrinkage shown in casting proper.

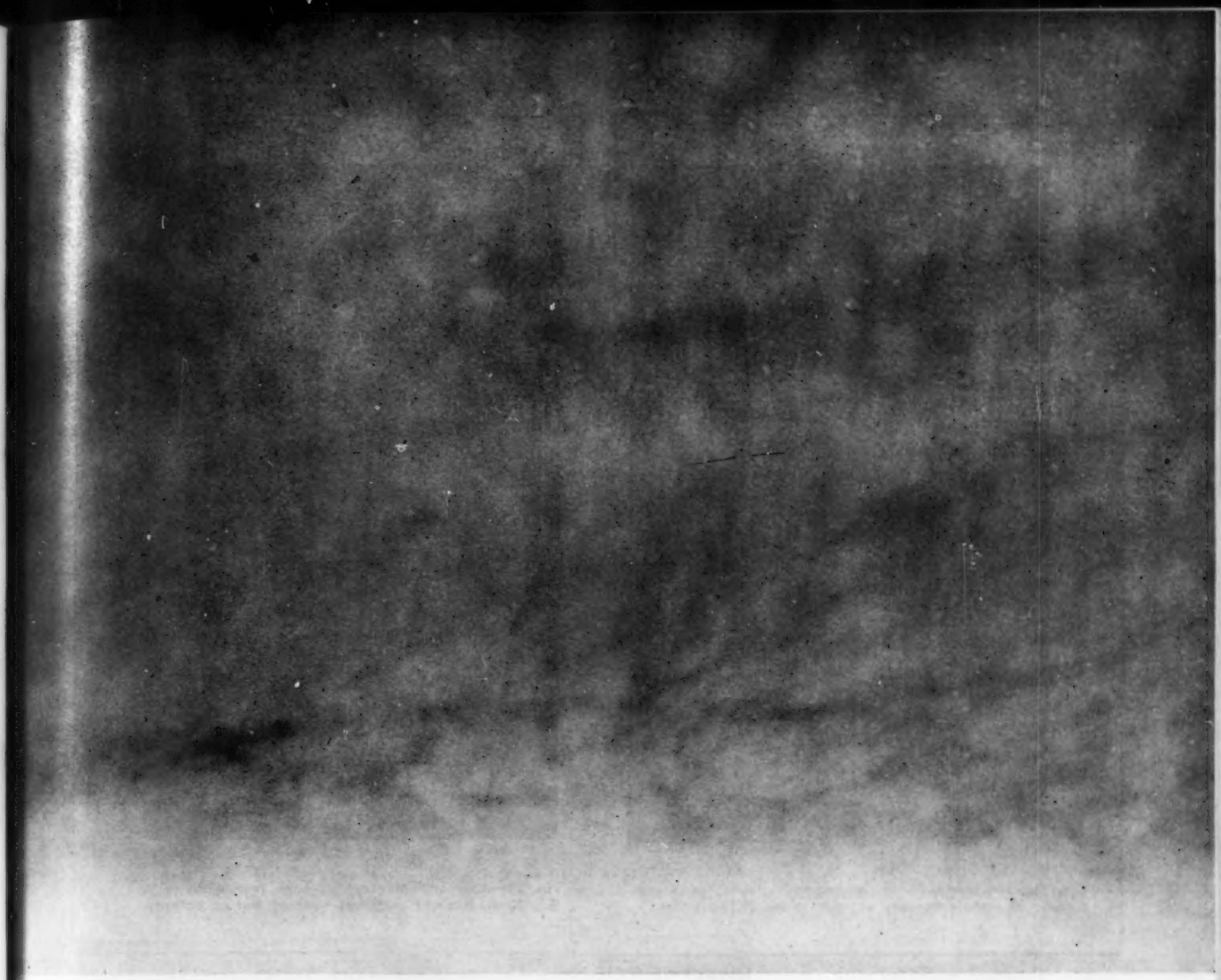


Fig. 19—Another ring casting section, overall height 12 in. Radiograph shows severe shrinkage or hot tears extending far down into casting.

tioned the interpretation of the films. However, when this casting was determined to be solid with the exception of that section near the gate, doubt was loudly expressed by a number of the foundry technicians. While the casting did show a few surface imperfections at this point, the radiographer held to the original interpretations that the shadow markings were internal defects or, in other words, shrinkage.

Proof was established by burning out this section with the carbon arc. This one instance, which happened a number of years ago, was the turning point for the skeptics in this foundry.

The logical step to follow in chronological order was to change the position of the gate, since the original purpose had been realized. This was accomplished by gating into each riser at the joint, as shown in Fig. 10. Because there was no shrinkage in the previous design, except at the gate, none was expected by this method, and this assumption is clearly evidenced by a typical junction, as shown in Fig. 11. Needless to say, this method was then adopted for production.

An interesting application happened several years ago when the foundry was called upon to make a strainer casing for service under high temperature and pressure. Since no core shift could be tolerated, it was thought necessary to hold the large core in place by a heavy rod anchor extending through the cope.

It was known that the anchor would have to be removed and the casting repaired, but the engineers said they could make a threaded plug so tight that it could not be found. After drilling out the anchor rod the hole was threaded and a plug fitted into the center of the wall section, leaving a depression of approximately ¼-in. on each side to be welded.

The radiograph, as shown in Fig. 12, revealed just how tight this "tight" plug fitted. Of course, this could not be permitted, so the plug was removed and the hole welded by placing a backing strip on the inside. The radiograph (Fig. 13) then showed an acceptable and uniform structure. Incidentally, the anchor method was quickly discarded and other means used to hold the core in a central position.

Another pattern was for an enclosed type motor shell which had two large pole pieces on the inside. These were in such a position that it was almost impossible to reach them with an open riser, and in-

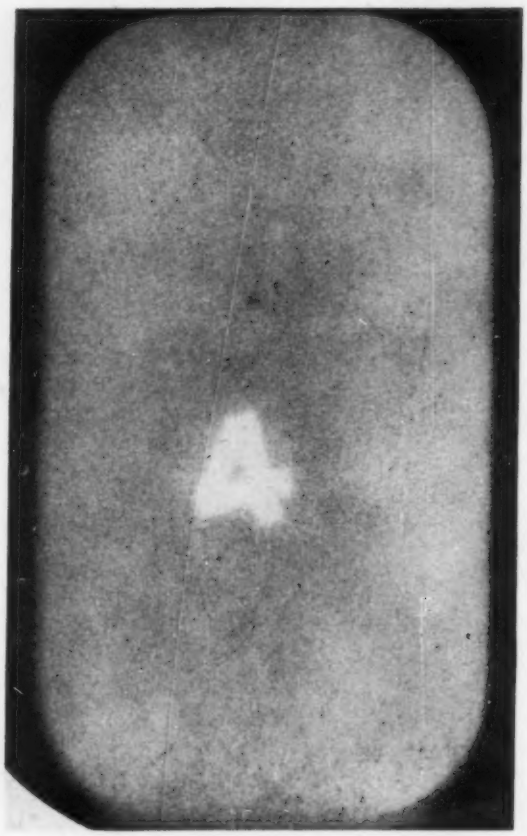


Fig. 20—Example of misleading radiograph. Appearance of pinhole porosity was due to use of faulty film.

Fig. 21—Another radiograph of same section shown in Fig. 20 shows slight centerline weakness but no porosity.

volved considerable pattern expense and time to provide a blind riser. Since they were fairly large castings and it was not wished to destroy any, it was decided to make two molds, one without any feeding at the pole pieces and one with an internal chill.

The radiographs, Figs. 14 and 15 respectively, determined that neither method would be satisfactory since, as was expected, the one showed a large shrink and the other the unfused chill. There was then only one method left, and that was to provide a pressure riser. Figure 16 shows that this should have been done in the first place, regardless of time and expense.

Even after the radiograph reveals the presence of internal defects it is not always possible to immediately diagnose the trouble so that a subsequent occurrence will be prevented. A ring casting of 36-in. diameter, 3¼-in. thickness and 6-in. height had been in production for some time without any shrinkage troubles being experienced.

It was designed with an open ring riser bottom gate and the mold filled from the gate, i.e., no metal was poured into the riser. Not long ago three of these rings were cast in the same heat and, as far as could be ascertained, all had been poured in a conventional manner. Since these castings are shipped to the customer without removing the riser, they of course are inspected with the riser attached to the casting.

An alert inspector noticed that the shrinkage cavities in one of the risers looked deeper than in the others. Visual inspection and inserting wires seldom give the true depth of these cavities. Furthermore, since the customer removed the riser, the foundry did not wish to deliver a defective casting, so it was decided that the quickest and least expensive method to determine the depth of the shrinkage was to radiograph these castings.

As in previous examples, it is not deemed necessary to exhibit all of the films, so only one radiograph on each casting will be used to demonstrate the problem. The first ring, with an overall height of 12 in. from the bottom of the casting to the top of the riser, did not have any shrinkage in the casting proper, as is shown in Fig. 17. The second ring, as is shown in Fig. 18, while it showed no shrinkage had an overall height of only 11½ in.

The third ring, with an overall height of 12 in. (Fig. 19), exhibited severe shrinkage or hot tears which extended far down into the casting. While the cause of this anomaly is still being discussed, with no logical answer as yet forthcoming, it certainly demonstrates the use of radiography for maintaining a supplier's integrity.

Sometimes the interpreter may be misled by his own films unless he is very careful, as in the following case. A light, cup-shaped casting

with four protruding feet was radiographed to determine the solidity at the junction. One of the feet, as shown in Fig. 20, was interpreted at first as showing fine pinhole porosity, but the others were clear.

The foot itself occupies only the light rectangular portion of the film. There being some question as to the cause of the porosity in one foot and not the others, the film was again placed on the viewing box. This time, possibly because the rheostat was turned higher, thereby increasing the light-intensity, the same type of shadow markings was observed on the film in the area outside of the casting or, so to speak, in the air.

Another radiograph was taken immediately (Fig. 21), which showed nothing but a slight center-line weakness. The only difference between the two radiographs was the film, and it had been taken from the same box. No satisfactory explanation has as yet been found, even after submitting the films to the manufacturer.

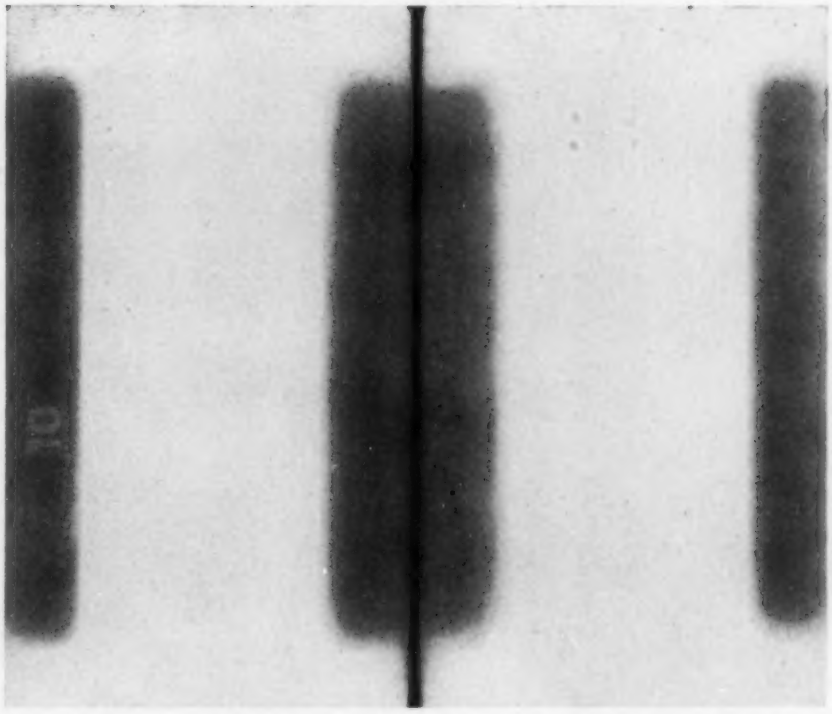


Fig. 23—Same section shown in Fig. 22 appears very clearly on "Type A" film under conditions of strong illumination.

This illustration is given only to serve as a warning to the observer so that he will not be too hasty in his interpretation of the shadow markings. It might also be mentioned at this point that it is good policy to mark the surface imperfections with small arrows before exposing the film. This partially eliminates controversy as to whether a shadow marking is external or internal, and helps immensely in locating internal defects so that they can be marked on the surface for subsequent removal and repair.

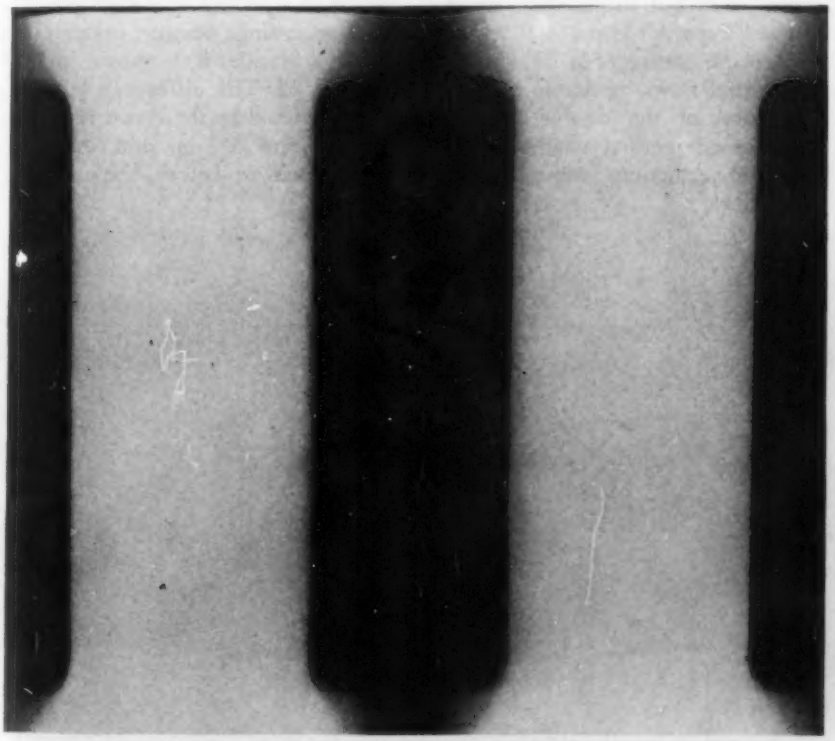


Fig. 22—Example of method using two films of different speeds in the same holder. Film density for ¾-in section when exposed for 2⅜-in. section is entirely too high for proper interpretation on this "no screen" film.

Exposure Methods

The satisfactory showing of wide variations in thickness by one exposure has always been a problem. The first method used was to expose two films of the same speed in one holder and reduce the exposure time by approximately 40 per cent. The thicker sections were then viewed through the two films superimposed upon each other, and the thinner sections through one film, but the method was not entirely successful.

The high-intensity illuminator with a variac control has been used with considerable success for a number of years. With this method only one film is exposed to conform to the greater thickness and the denser portion of the film viewed with the high-intensity illumination. The latest innovation is the use of two films of different speeds in the same holder. We are indebted to Seeman and Corney[11] for the suggestion, to Taylor[9] for the actual development.

By a combination of the last two methods we are able to observe wide

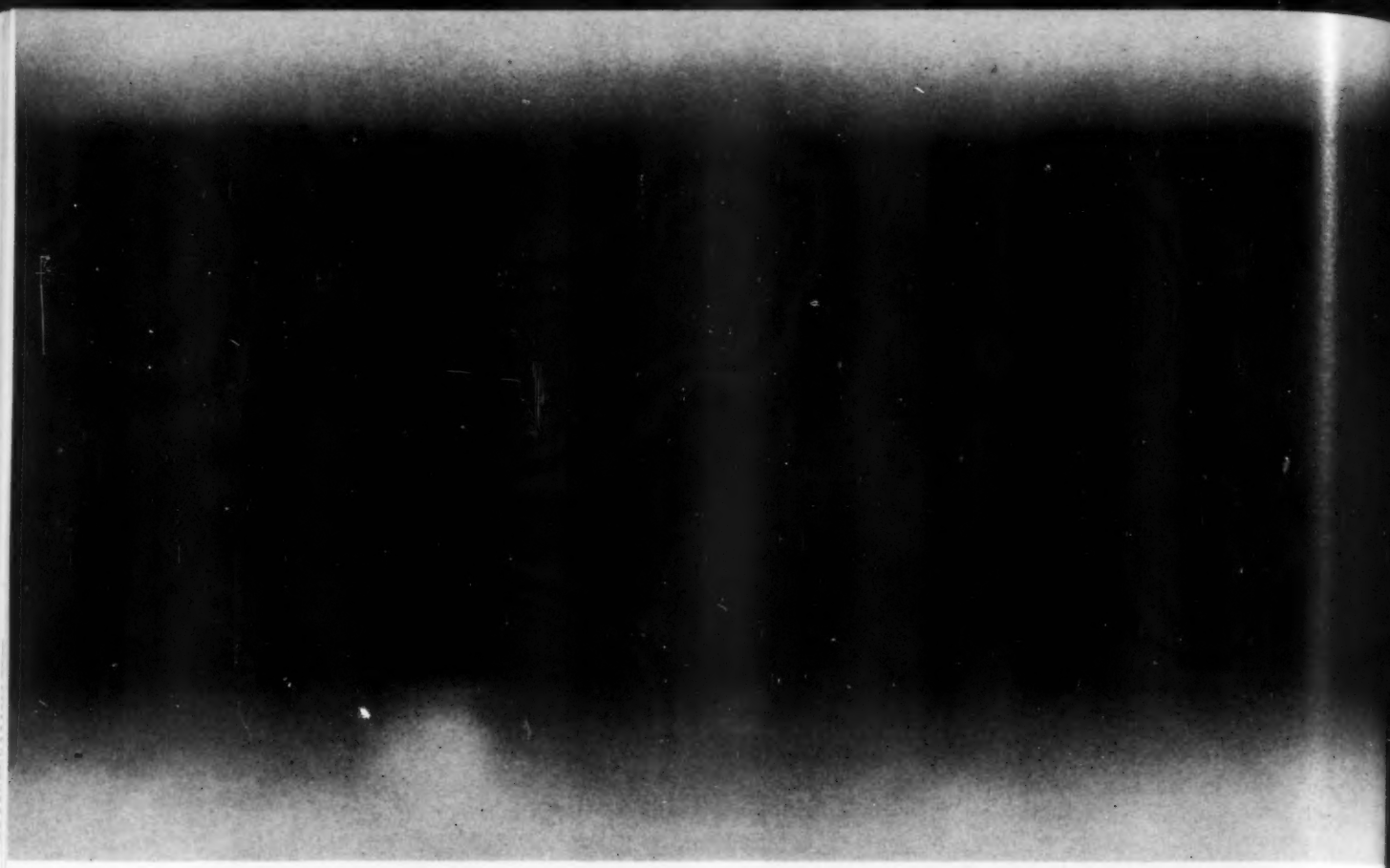


Fig. 24—The double film-different speed method applied to casting section thicknesses of 1¼ in. and 3¾ in. Exposed for the 3¾-in. thickness, only faint differences in density for the thin portion appear on the "no screen" film under strong illumination.

variations with one exposure. Figures 22 and 23, using films of different speeds, show a small casting with the thickness ranging from ¾-in. to 2⅜-in. ("no screen" and "Type A" film respectively). The ¾-in. metal, when exposed for a 2⅜-in. section, gives a film density entirely too high for proper interpretation on the "no screen" film but shows very clearly on the "Type A" film.

Since the casting (Fig. 23) showed no internal flaws, probably a better illustration of the double film-different speed method would be one where imperfections were detected in the thinner section. The radiograph of a section of a high pressure turbine casing, coming under Class 2 Navy Standards, is shown in Figs. 24 and 25. The difference in thickness depicted in these two films was 1¼-in. and 3¾-in. and the same types used as before, exposing for

Fig. 25—Gas holes appearing in same section shown in Fig. 24 on "Type A" film under ordinary illuminating conditions.

the 3¾-in. thickness.

Figure 24 is the "no screen" film, and under the strongest light available, namely, two no. 1 photofloods, only faint differences in density could be observed in the thin portion. Figure 25 is the "Type A" film, and under ordinary light numerous gas holes can be clearly seen. Without this double-film method it would have been necessary to make another exposure for the 1¼-in. section.

While the author has used this method for only a short time, it is believed that it has wide possibilities. There are a number of other combinations of different-speed films that can be used and which it is intended to try. In the last illustration shown there was a difference of 2½ in. between the wall thickness, but it is probable that with the proper films differences of 4 in. can be shown with satisfactory density.

Conclusion

In concluding, it might be said that there are numerous other examples of radiography for the development of foundry technique, not only in this shop but in many other places. The value of this method is clearly evidenced by the few examples cited. Without the use of radiography, the development of these castings would have been time consuming and expensive since it would have necessitated their destruction by sawing or machining for visual examination. It would not only have been dangerous but perhaps have caused a loss of prestige and valuable machining time if these castings had been delivered without examination.

In a certain bureau of the government there is a saying that it is better to protect than detect. This surely can be applied to the foundry industry, since it would be much better for the producer to protect himself by radiographic inspection than to have the imperfection detected by the consumer. Radiography may have been a burden at one time, but it is now a necessity and is here to stay.

Acknowledgment

The author wishes to express his appreciation to R. E. Fisher, President, Bonney-Floyd Co., for his permission to publish this discussion. He is also deeply indebted to Dr. C. H. Lorig, Battelle Memorial Institute, for the preparation of the slides.

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Comparison of the Common American and European Magnesium Casting Alloys

By L. W. Eastwood, Assistant Supervisor, James A. Davis and James DeHaven, Research Engineers, Battelle Memorial Institute, Columbus, Ohio

• As part of the general program sponsored by the Office of Production Research and Development of the War Production Board, and under the guidance of the Office of Scientific Research and Development, an extensive investigation of the properties and characteristics of the most commonly used American and European magnesium casting alloys was conducted and is presented comparatively.

THE initial development of the magnesium casting industry must be largely credited to Germany. This initial development was carried to England and to the United States where the industry was further developed but along slightly different directions. Probably the outstanding divergence lies in the selection of alloys.

The three most widely used European alloys are designated AZG, A-8, and AZ-91. Initially, binary magnesium-aluminum alloys were used, but in recent years the American casting industry has been developed largely around two alloys, ASTM-4 and ASTM-17, the former being similar in comparison to the European alloy known as AZG.

Four Alloys Used

ASTM-4 alloy has been by far the most popular casting alloy in the United States. The second alloy widely used and known as ASTM-17 is not generally used in European foundries, excepting experimentally. Since the composition of ASTM-4 and AZG are similar, there remain but four different compositions which represent the chief casting alloys of this country and Europe. Typical compositions of these four alloys are shown in Table 1.

It will be noted that all of these compositions contain aluminum as the principal alloying constituent, and that they all contain similar amounts of manganese, which is added to increase the resistance of the alloys to corrosion. The main differences lie in the zinc content. While these composition differences are not great, it will be shown that there are considerable and very important differences among the four alloys.

It should be noted at this point that Britain definitely discourages the use of AZG, the ASTM-4 composition, for high-quality aircraft castings where high strength is important. Britain specifies the AZ-91 composition, heat treated and aged, where high yield strength is required. Where a high degree of ductility and toughness, as in landing wheels for aircraft, is required, the A-8 composition in the heat-treated condition is specified.

The ASTM-4 composition, widely used in the United States for aircraft parts, is not considered to be sufficiently reliable to warrant its use for these critical parts. It should also be noted at this point that investigations of German aircraft shot down during the war show that the A-8 and AZ-91 compositions are both widely used for casting purposes. The AZG or ASTM-4 composition is used to a relatively small extent and then generally for unstressed parts, in as-cast condition.

Table 1

MAGNESIUM ALLOY COMPOSITION

Alloy Designation	*—Components, per cent—* Al	Zn	Mn
AZ-91	9.6	0.4	0.2
A-8	8.0	0.4	0.2
AZ or ASTM-4	6.0	3.0	0.2
ASTM-17	9.0	2.0	0.2

As a part of the project sponsored by the Office of Production Research and Development of the War Production Board at Battelle, a comparison of the four alloys was undertaken in respect to:

(1) Tensile properties of separately cast bars; (2) tensile and Charpy impact properties at room temperature and at —75° F.; (3) fatigue limit; (4) susceptibility to hot shortness or hot cracking; (5) susceptibility to the occurrence of microporosity; (6) resistance to corrosion and the effects of iron content upon this resistance; (7) amenability to heat treatment; (8) solidification range; (9) leak tightness; (10) amenability to degassing operations; and (11) amenability to grain-refining operations.

Comparison of Tensile Properties

The tensile properties, namely, ultimate strength, yield strength, and per cent elongation, were obtained on separately cast bars shown by Fig. 4 of Reference 1. This test casting is the four-bar type recommended by the Dow Chemical Co. The melts were prepared according to present commercial practices and by the chlorine flux, carbon inoculation method, using alloys pur-

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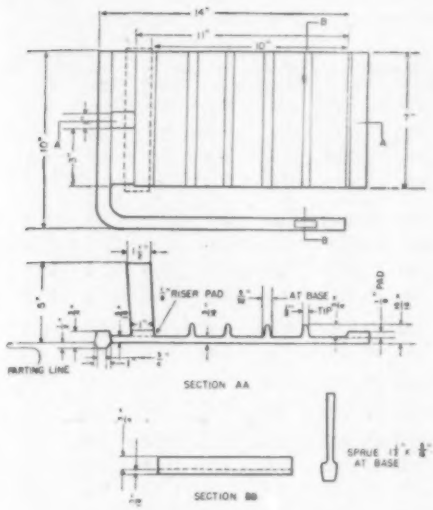

Fig. 1—Sectional views of 6x10x3/16-in. ribbed plate test casting.

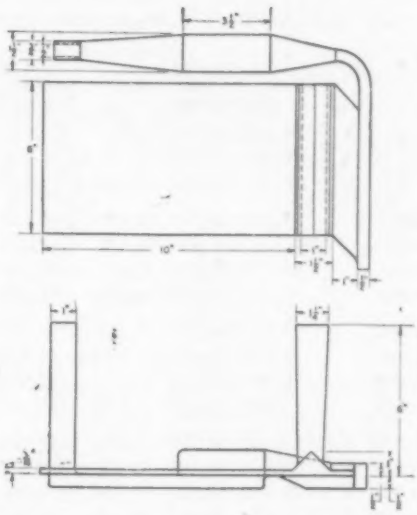

Fig. 2—Views of 6x10x3/16-in. plain plate test casting.

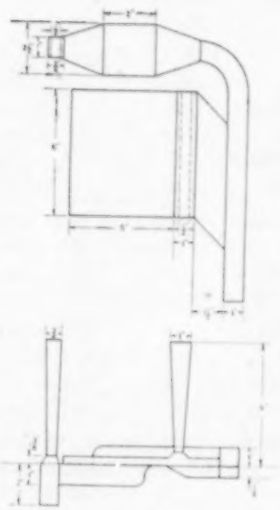

Fig. 3—Test casting, 5x6x3/8-in. plain plate.

chased from various ingot producers.

The bars were then heat treated to produce a good quality heat treatment as determined by microscopical examination. In general, the Dow ratings for undissolved constituents were always less than no. 4 and usually no. 2 or better. The grain sizes and soundness were also checked to make certain that good quality bars were obtained.

Tensile properties were, therefore, obtained on sound bars given a nearly perfect heat treatment regardless of the alloy composition and irrespective to the difficulties encountered, or the relative amenability of the various compositions to heat treatment. The relative amenability of the various compositions to heat treatment was considered separately.

ASTM-4 alloy was heated from 500 to 720° F. in 5 hr., held at 720° F. 17 hr., and quenched in oil. Aging was effected in 16 hr. at 400° F. ASTM-17 alloy was heated from 500 to 770° F. in 6½ to 7 hr., held at 770° F. 16 hr., heated to and held at 780° F. for 4 hr., then cooled to 770° F. and oil quenched. The aging treatment consisted of 16 hr. at 400° F. A-8 and AZ-91 alloys were heat treated with ASTM-17 alloy, but A-8 was withdrawn before increasing the temperature to 780° F.

These alloys were also oil quenched and aged the same as the other alloys. The results obtained on many bars of several different heats are listed in Table 2. This table shows the number of bars tested, the minimum and average tensile, yield, and elongation values for the four different alloys in the as-cast, heat-treated, heat-treated and aged, and in the annealed conditions.

In general, these results show that ASTM-4 and A-8 are more or less comparable. More precisely, the data show that ASTM-4 has the best combination of tensile strength and ductility in the as-cast condition. A-8 has only slightly lower ductility in the as-cast condition as compared with ASTM-4 alloy. AZ-91 and ASTM-17 alloys are, of course, very brittle in the as-cast condition, but normally these alloys would never be recommended for use in this condition.

In the heat-treated and in the heat-treated and aged condition, ASTM-4 and A-8 are comparable, while AZ-91 and ASTM-17 have similar tensile properties. The data show that A-8 is slightly superior to ASTM-4 in the heat-treated condition and slightly inferior in the heat-treated and aged condition. ASTM-17 is also slightly superior to AZ-91 in the heat-treated and aged condition, but these two alloys are comparable in the heat-treated condition.

It should be emphasized that the properties listed in Table 2 represent data on bars which have almost a complete solution of the aluminum-magnesium constituent, a condition which is maintained by cooling them rapidly from the solution heat-treating temperature by means of an oil quench. The data in no way reflect the relative difficulties encountered when heat treating the four different compositions.

The tensile properties of A-8 and AZ-91 are somewhat higher than those reported by English foundries. The four-bar and English D.T.D. bar[2] for light alloys were compared and the data obtained are listed in Table 3. It will be noted that the four-bar frequently produces higher properties, particularly higher elongation values and higher minimum properties.

It can be safely assumed that the higher properties of A-8 and AZ-91 are at least in part caused by the difference in test-bar design. The tensile properties obtained on ASTM-4 and ASTM-17 alloys are also somewhat higher than average properties obtained in American foundries using a similar test-bar design. This can probably be attributed to the high order of soundness and the consistently ideal heat treatment obtained.

The tensile-impact specimens were machined from the cast-to-size tensile bars, and they were heat treated as described in the foregoing to pro-

Table 2

TEST BAR PROPERTIES OF ASTM-4 AND 17, A-8, AND AZ-91 IN THE AS-CAST, HEAT-TREATED, HEAT-TREATED AND AGED, AND ANNEALED CONDITIONS

Alloy	No. of Bars	Heat Treatment	Tensile Strength, psi. Min.	Tensile Strength, psi. Avg.	Tensile Strength, psi. Max.	Yield Strength, psi. Min.	Yield Strength, psi. Avg.	Yield Strength, psi. Max.	Elongation in 2 In., per cent Min.	Elongation in 2 In., per cent Avg.	Elongation in 2 In., per cent Max.	Reduction in Area, per cent Min.	Reduction in Area, per cent Avg.	Reduction in Area, per cent Max.
ASTM-4	58	As cast	27,300	30,700	33,100	12,000	14,000	16,300	3.6	6.4	8.6	3.6	6.5	10.3
A-8	14	As cast	24,500	26,800	28,600	13,400	15,400	17,500	3.1	4.1	4.7	3.2	4.9	6.3
ASTM-17	44	As cast	21,500	24,500	26,500	14,600	17,500	19,300	0.4	1.3	2.7	0.4	1.4	2.8
AZ-91	20	As cast	21,700	23,800	25,800	13,900	16,800	18,800	0.0	1.0	2.5	0.0	1.2	2.4
ASTM-4	146	H.T., oil quench	37,100	40,700	43,800	11,200	13,350	16,550	10.6	14.1	17.9	7.5	16.2	25.0
A-8	36	H.T., oil quench	39,000	41,300	42,600	12,600	13,800	15,700	12.1	16.0	17.8	12.5	17.6	19.9
ASTM-17	16	H.T., oil quench	40,900	43,600	45,100	14,500	15,600	17,300	10.5	13.4	15.5	12.1	15.4	19.9
AZ-91	33	H.T., oil quench	38,900	42,400	43,800	11,600	14,700	15,900	10.5	13.4	17.0	11.4	15.3	17.3
ASTM-4	116	H.T.A., oil quench	32,900	40,100	44,300	16,200	19,200	22,800	0.6	6.0	8.8	1.2	6.5	10.2
A-8	35	H.T.A., oil quench	33,200	38,400	41,000	17,400	19,300	21,500	2.4	4.0	5.9	2.0	3.9	6.3
ASTM-17	18	H.T.A., oil quench	38,300	42,700	46,200	23,900	25,900	29,400	0.8	2.1	4.0	0.0	1.9	4.0
AZ-91	34	H.T.A., oil quench	35,500	39,400	42,000	20,200	23,500	25,800	0.6	2.0	3.1	0.4	2.6	3.9
ASTM-4	4	Annealed 16 hr. at 550° F.	29,100	30,700	32,200	15,300	15,800	16,400	4.7	5.8	6.4	3.6	5.9	7.8
	2	Annealed 16 hr. at 400° F.	26,800	28,700	30,600	16,300	16,700	17,000	2.5	3.3	4.0	2.4	3.2	4.0
A-8	2	Annealed 16 hr. at 550° F.	25,600	26,100	26,500	16,900	17,000	17,100	3.0	3.1	3.3	2.4	2.8	3.2
	2	Annealed 16 hr. at 400° F.	27,600	28,900	30,100	16,600	17,400	18,100	2.3	2.5	2.7	1.6	1.7	1.8
ASTM-17	4	Annealed 16 hr. at 550° F.	24,700	25,800	26,400	18,300	18,700	19,400	1.3	1.6	1.9	1.2	1.7	2.4
	2	Annealed 16 hr. at 400° F.	24,400	26,100	27,800	18,400	18,800	19,100	0.1	0.6	1.1	0.0	0.4	0.8
AZ-91	3	Annealed 16 hr. at 550° F.	24,400	24,800	25,200	18,200	18,800	19,100	1.4	1.4	1.4	0.4	0.9	1.2
	2	Annealed 16 hr. at 400° F.	23,500	24,400	25,300	17,700	18,400	19,000	0.4	0.4	0.4	0.4	0.4	0.5

duce an essentially perfect solution heat treatment without burning. The tests were carried out on a standard Riehle impact machine equipped with a redesigned tup of the same calibration as the original tup. This tup is constructed so that the specimens may be quickly inserted when running tests at temperatures above or below room temperature.

Tests were conducted at room temperature and at —75° F. on all four alloys in the as-cast, in the heat-treated, and in the heat-treated and aged conditions. It was found that the results obtained at —75° F. were practically identical to those obtained at room temperature, and consequently the results are not separately reported, but all the results obtained at the two temperatures are averaged (Table 4).

This table shows the number of bars tested and the minimum average and maximum values obtained on elongation, reduction in area, and impact value. The data in this table show that the results are quite similar to those obtained on the tensile test. Again ASTM-4 is slightly the best in the as-cast condition. ASTM-4 and A-8 are comparable in the heat-treated condition, while AZ-91 and ASTM-17 are also comparable in the heat-treated condition. In the heat-treated and aged condition, however, ASTM-4 and ASTM-17 are slightly superior to A-8 and AZ-91 alloys, respectively.

The Charpy impact values obtained on the four alloys at room temperature and at —75° F. are listed in Table 5. The results parallel the tensile-impact results, but there seems to be some adverse effect from the low temperature. Probably, however, additional results would be required to establish definitely this adverse effect.

The R. R. Moore rotating-beam machine and specimens were used

Table 3

COMPARISON OF ENGLISH D.T.D. TEST BAR AND AMERICAN 4-BAR CASTINGS

Alloy	Test Bar	Heat Treatment	Tensile Strength, psi. Min.	Tensile Strength, psi. Avg.	Yield Strength, psi. Min.	Yield Strength, psi. Avg.	Elongation in 2 In., per cent Min.	Elongation in 2 In., per cent Avg.	Reduction in Area, per cent Avg.
ASTM-4	4-bar	A.C.	23,400	29,300	14,500	15,200	2.4	5.3	6.5
	D.T.D.		17,100	28,200	13,000	13,800	0.9	3.0	5.3
	4-bar	H.T.	40,400	42,000	13,900	14.100	13.1	15.7	18.3
	D.T.D.		31,600	39,500	12,600	13,000	7.1	14.1	16.1
	4-bar	H.T.A.	39,000	41,400	18,800	19,900	4.7	6.1	5.9
	D.T.D.		39,300	41,700	17,300	19,000	5.9	7.7	8.1
A-8	4-bar	A.C.	23,800	26,000	13,900	14.900	2.5	3.8	4.0
	D.T.D.		24,600	25,000	12,700	13,200	3.5	4.2	4.3
	4-bar	H.T.	38,800	40,400	12,200	13,000	11.6	14.8	15.4
	D.T.D.		33,700	39,200	12,200	12,900	8.7	13.7	13.5
	4-bar	H.T.A.	36,600	37,100	17,700	19,000	3.2	3.8	4.8
	D.T.D.		37,700	38,200	16,000	18,600	1.1	4.2	4.4
ASTM-17	4-bar	A.C.	23,800	25,000	17,300	17,700	0.9	1.1	1.9
	D.T.D.		21,700	22,700	14,500	16,000	0.8	1.2	1.5
	4-bar	H.T.	38,500	42,400	14,400	15,300	9.2	12.7	14.3
	D.T.D.		36,800	39,000	12,900	13,900	8.5	10.8	11.9
	4-bar	H.T.A.	33,800	39,800	23,700	25,300	0.6	1.7	1.1
	D.T.D.		33,700	37,300	19,900	21,200	0.6	1.6	2.2
AZ-91	4-bar	A.C.	22,800	23,400	16,200	16,800	0.9	1.6	2.0
	D.T.D.		19,000	21,200	14,800	15,600	0.5	1.1	1.6
	4-bar	H.T.	40,800	42,300	13,500	14,100	10.4	13.6	15.0
	D.T.D.		38,000	40,200	13,100	13,800	9.6	12.6	14.1
	4-bar	H.T.A.	28,900	37,400	20,400	22,700	0.1	1.5	1.1
	D.T.D.		35,100	37,600	19,900	20,700	0.8	1.7	1.9

Table 4

TENSILE-IMPACT VALUES FOR FOUR ALLOYS IN THE AS-CAST, HEAT-TREATED, AND HEAT-TREATED AND AGED CONDITIONS TESTED AT ROOM TEMPERATURE AND AT —75° F. (TUP SPEED 18.1 FT./SEC.)

Alloy	No. of Bars	Heat Treatment**	Elongation in 2 In., per cent — Min.	Avg.	Max.	Reduction in Area, per cent — Min.	Avg.	Max.	Impact Value, ft.-lb. — Min.	Avg.	Max.	Remarks
AS-CAST ALLOYS												
ASTM-4	6	A.C.	4.0	4.7	5.5	3.2	4.1	4.8	10.0	12.5	15.5	Tested at — 75° F.
Avg.*	24	A.C.	3.8	5.3	6.5	3.2	5.1	6.1	10.0	14.4	19.0	
A-8	2	A.C.	3.4	3.5	3.6	3.2	3.2	3.2	8.5	9.0	9.5	Tested at — 75° F.
Avg.*	8	A.C.	3.2	3.2	4.4	2.4	3.3	4.8	7.5	8.8	13.0	
ASTM-17	2	A.C.	0.7	1.0	1.3	0.8	1.2	1.6	3.0	3.5	4.0	Tested at — 75° F.
Avg.*	12	A.C.	0.6	1.0	1.9	0.8	2.0	3.2	2.5	3.4	6.0	
AZ-91	2	A.C.		0.9		0.8	0.8	0.8	3.0	3.0	3.0	Tested at — 75° F.
Avg.*	8	A.C.	0.4	0.8	1.4	0.8	0.8	0.8	3.0	3.6	5.0	
HEAT-TREATED ALLOYS												
ASTM-4	2	H.T.	12.1	12.6	13.2	10.1	10.9	11.7	33.0	34.2	35.5	Coarse grain, 0.008 in.†
	4	H.T.	8.5	13.2	18.8	7.9	12.4	18.8	23.7	45.0	69.5	Tested at — 75° F.
Avg.*	18	H.T.	8.5	15.2	20.5	7.9	15.2	23.2	23.7	49.0	69.5	
A-8	4	H.T.	9.5	13.2	18.3	8.6	13.2	16.8	32.0	47.5	68.7	Tested at — 75° F.
Avg.*	9	H.T.	9.5	15.0	19.6	8.6	15.0	21.0	32.0	51.0	68.7	
ASTM-17	2	H.T.	14.7	16.7	18.8	13.8	15.3	16.8	56.5	64.0	71.5	Tested at — 75° F.
Avg.*	8	H.T.	14.7	17.2	20.6	13.8	17.4	18.8	50.0	60.6	71.5	
AZ-91	2	H.T.	16.5	17.3	18.1	14.5	15.0	15.5	61.5	64.0	66.5	Tested at — 75° F.
Avg.*	8	H.T.	14.2	16.9	18.1	14.5	17.1	19.6	48.0	59.0	66.5	
HEAT-TREATED AND AGED ALLOYS												
ASTM-4	6	H.T.A.	5.0	5.6	6.1	4.7	5.5	6.3	20.2	24.2	30.2	Tested at — 75° F.
Avg.*	25	H.T.A.	4.3	6.0	8.2	4.0	5.4	8.6	17.0	24.4	31.0	
A-8	4	H.T.A.	4.0	4.2	4.7	4.0	4.6	4.8	18.7	19.2	20.0	Tested at — 75° F.
Avg.*	10	H.T.A.	3.6	4.3	5.3	4.0	5.7	7.8	17.5	19.1	21.0	
ASTM-17	2	H.T.A.	2.6	2.6	2.7	2.4	2.8	3.2	16.0	16.2	16.5	Tested at — 75° F.
Avg.*	8	H.T.A.	1.3	2.2	3.6	2.4	3.6	4.8	8.0	13.9	21.5	
AZ-91	5	H.T.A.	0.9	1.3	1.7	1.6	1.7	2.4	7.0	9.2	11.0	Tested at — 75° F.
Avg.*	11	H.T.A.	0.9	1.4	2.2	1.6	2.1	3.2	7.0	9.6	14.0	

*Since the results at —75° F. were substantially the same as at room temperature, these results have been averaged with those obtained at room temperature.
**Oil quenched if heat treated.
†Coarse-grained bars not included in the averages.

for these tests. The specimens were machined from the cast tensile test bar and heat treated to produce practically complete solution, a condition which was maintained in the solution heat-treated casting by oil quenching it to room temperature.

The S-N curves were run out to 10,000,000 cycles on notched and standard specimens of all four alloys tested in the as-cast heat-treated, and heat-treated and aged conditions. The results are tabulated in Table 6.

In general, all of the alloys have the highest endurance limit in the solution heat-treated condition, the average being 14,950 psi. The as-cast condition is the next most favorable with an average of 13,650 psi., while the heat-treated and aged condition produced the lowest fatigue properties, the average for the four alloys being 12,870 psi. at 10,000,000 cycles.

ASTM-4, A-8, and AZ-91 alloys have comparable endurance values in the three conditions, while ASTM-17 in the solution heat-treated and in the solution heat-treated and aged conditions is slightly better than the other three alloys.

Magnesium-base alloys are quite subject to the formation of microporosity in castings. The susceptibility, however, varies with the composition. The factors which affect the formation of microporosity have been described[3], the alloy com-

Table 5

CHARPY IMPACT VALUES* FOR THE FOUR ALLOYS AT ROOM TEMPERATURE AND AT —75° F.

Alloy	Heat Treatment	Energy Absorbed, ft.-lb. at Room Temperature — No. of Bars	Min.	Avg.	Max.	at —75° F. — No. of Bars	Min.	Avg.	Max.
ASTM-4	As cast	4	2.0	2.0	2.0	4	0.75	1.5	2.0
A-8	As cast	2	2.0	2.2	2.5	3	1.25	1.3	1.5
ASTM-17	As cast	3	1.0	1.0	1.0	7	0.75	0.8	1.0
AZ-91	As cast	4	1.0	1.4	2.0	4	0.75	0.75	0.75
ASTM-4	H.T.	3	4.5	4.7	5.0	4	3.75	3.9	4.0
A-8	H.T.	4	5.0	5.1	5.5	4	3.75	3.75	3.75
ASTM-17	H.T.	4	4.5	4.8	5.0	4	3.0	3.4	3.75
AZ-91	H.T.	4	4.5	4.9	5.0	2	3.0	3.0	3.0
ASTM-4	H.T.A.	4	1.0	1.5	2.0	6	1.2	1.4	1.75
A-8	H.T.A.	4	1.0	1.5	2.0	2	1.0	1.0	1.0
ASTM-17	H.T.A.	4	1.0	1.2	1.5	4	0.5	0.6	0.75
AZ-91	H.T.A.	4	0.5	1.0	1.5	2	0.5	0.5	0.5

*Specimen was 0.315x0.394x2 in. with a "V" notch 0.08 in. deep with 0.01 in. bottom radius. Velocity of tup 18.1 ft./sec.

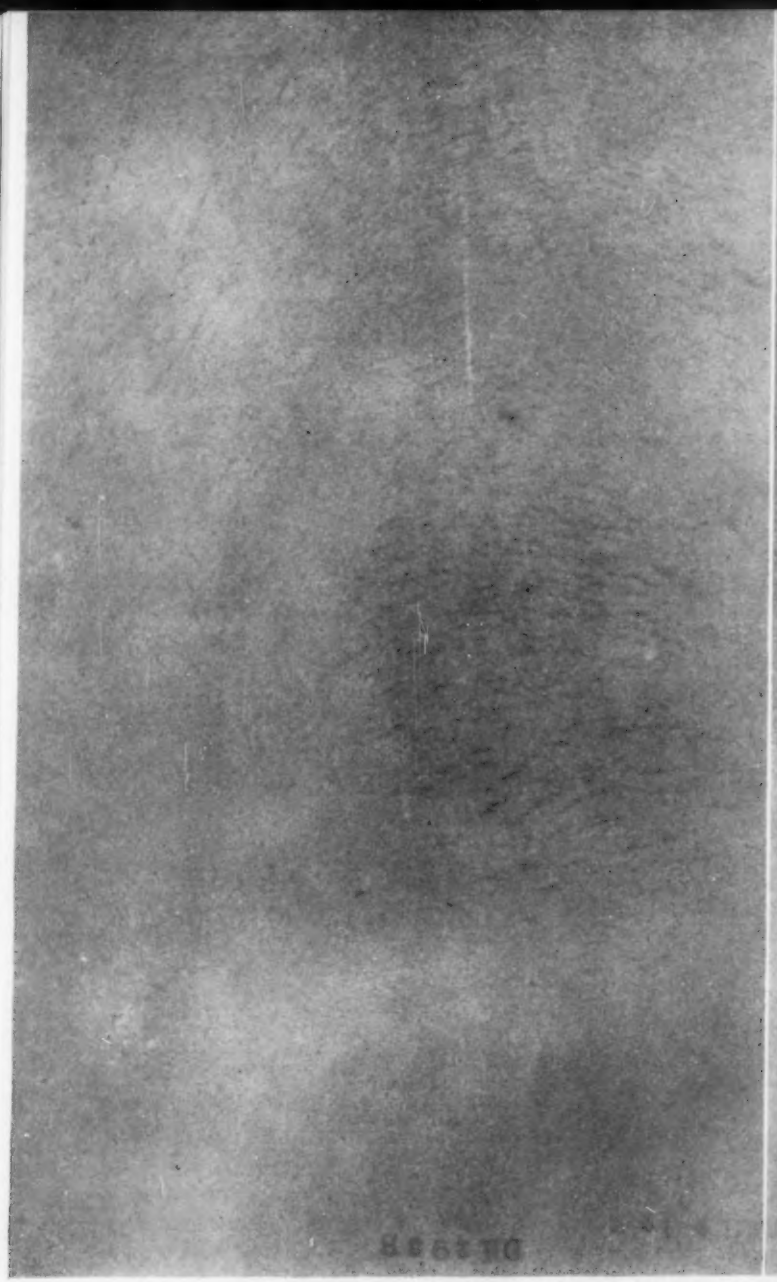

Fig. 4—ASTM-4 alloy 3/16-in. plain flat plate test casting with 1-in. riser at gate end (bottom of radiograph) only. Wedge data—height of sound metal, 3 in.—grain size, 0.006 in. Metal cleaned with chlorine and treated with natural gas. Considerable microporosity in two-thirds of the casting opposite the gate and riser is shown. The effect of alloy composition on the occurrence of microporosity in this plate is shown by comparison to Figs. 5, 6, and 7.

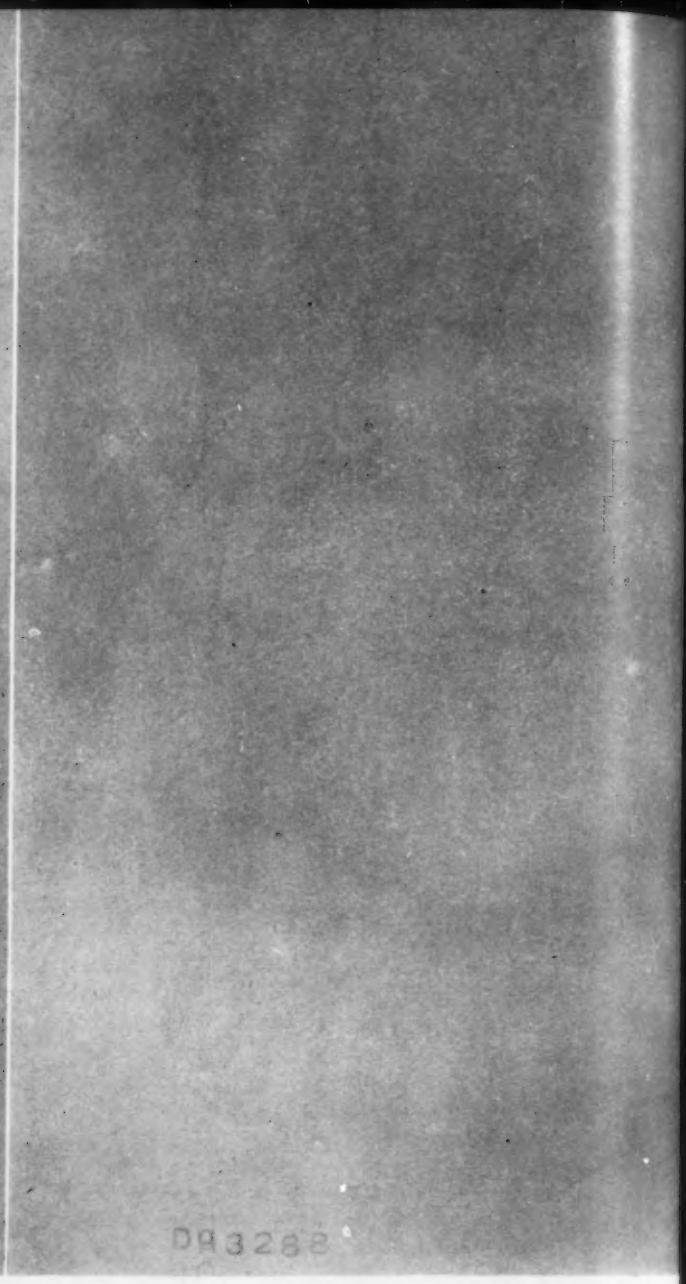

Fig. 5—ASTM-17 alloy 3/16-in. plate test casting with 1-in. riser at gate end (bottom of radiograph). Metal cleaned with chlorine and treated with natural gas. Wedge data—height of sound metal, 2¼ in.—grain size, 0.006 in. This casting is practically free from microporosity and, as compared with ASTM-4 alloy (Fig. 4), shows the lower susceptibility of this alloy to the formation of microporosity in thin plates.

position being one of three major factors. The susceptibility of the four alloys to microporosity was determined by the use of four different castings.

The first is a wedge casting shown by Figs. 1 and 2 of reference 1. The second casting used was a ribbed plate 3/16-in. thick by 6 in. wide and 10 in. long (Fig. 1). The third casting consisted of a plain 3/16-in. plate, 6 in. wide by 10 in. long (Fig. 2). The fourth casting consisted of a ⅜-in. plate (Fig. 3). All three of the latter plate castings could be risered in various ways, providing various degrees of feeding.

It has been found that the amount of microporosity varies considerably with the alloy composition. Typical results are shown by the reproduced radiographs of the 3/16-in. plate in Figs. 4, 5, 6, and 7 for ASTM-4, ASTM-17, A-8, and AZ-91 alloys, respectively. Figures 8, 9, 10, and 11 show a similar series of the ⅜-in. plates. All of these photographs of x-ray films are representative of the results obtained on a great many similar castings poured from a great many melts.

It has been found definitely that ASTM-4 alloys is markedly more susceptible to the formation of microporosity in the sections represented by the castings described than any of the other three alloys. AZ-91 and ASTM-17 are slightly superior to A-8 composition. The difference, however, between these two alloys and A-8 is much less than the difference between ASTM-4 and A-8. It may be concluded that A-8, AZ-91, and ASTM-17 are all markedly superior to ASTM-4 but

are quite similar to each other, A-8 being slightly more susceptible to the formation of microporosity than the other two alloys.

Susceptibility to Leaking

Leakage in magnesium-base castings is largely caused by the presence of microporosity, the intergranular voids extending across the section causing a leak. The test casting[4] shown by Fig. 12 was used to measure the susceptibility of the four alloys to microporosity and leakage. It was found that this casting leaked when poured in any one of the four alloys if the melt was gassy.

After degassing, however, AZ-91, ASTM-17, and A-8 compositions produced castings which were leak tight under 100 lb. of air pressure. However, all of the castings poured in ASTM-4 alloy leaked in the heavy sections. Only a relatively small amount of work was done with leak testing of this casting. The results, however, are in conformity with those found by other investigators[5]. There is, of course, a good correlation between the susceptibility to leakage and the susceptibility to microporosity formation.

Amenability to Degassing Operation

The method of measuring the gas content of the melt has been described in a separate paper[1]. It was found, however, that no noticeable difference in the height of sound metal in the wedge casting could be observed among the four different compositions. The best that could be produced with any of the compositions was about 3½ in. of sound metal in the bottom of the wedge.

It was noted, however, that A-8, AZ-91, and ASTM-17 alloys could be degassed slightly more readily than the ASTM-4 melts to obtain 3½ in. of sound metal in the wedge. It was concluded, however, that there is no practical difference among the four alloys in their amenability to a degassing operation such as that described elsewhere using chlorine or a mixture of chlorine and carbon tetrachloride.

Amenability to Grain Refining

All four alloys are subjected to various grain-refining operations as described in a separate paper[6]. Some investigators have reported a slight difference among the various alloys in respect to their response to a grain-refining treatment[7].

It has been noted in a separate paper that aluminum must be in the melt before grain refinement can be obtained by present methods. However, all four of the alloys in question have a substantial amount of aluminum, and no perceptible difference in their response to the grain-refining treatment could be noted. Indeed, all four of the alloys responded quite similarly to grain-refining and grain-coarsening treatments.

Table 6

Endurance Properties of the Four Alloys†

Alloy	Heat Treatment	Endurance Limit, psi. (10 Million Reversals)		
		Cast to Size, Unnotched*	Machined Bars	
			Unnotched*	Notched**
ASTM-4	A.C.	13,000	12,600	9,000
A-8	A.C.		14,200	10,000
ASTM-17	A.C.		13,500	10,000
AZ-91	A.C.		14,300	10,000
ASTM-4	H.T.	15,000	13,700	11,000
A-8	H.T.		15,500	10,000
ASTM-17	H.T.		16,500	13,000
AZ-91	H.T.		14,800	11,500
ASTM-4	H.T.A.	12,000	12,700	10,000
A-8	H.T.A.		12,500	9,000
ASTM-17	H.T.A.		14,000	8,000
AZ-91	H.T.A.		12,300	9,000
ASTM-4	Annealed***		11,500	9,000
A-8	Annealed		13,000	9,500
ASTM-17	Annealed		13,500	9,000
AZ-91	Annealed		12,000	9,500

*Standard R. R. Moore 0.300-in. diameter.
**0.360-in. diameter bar with a 0.030-in. radius notch.
***Annealed 4 hr. at 400° F.
†The endurance value for the standard bar in the as-cast, heat-treated, and heat-treated and aged conditions is the result of three S-N curves. Those for the annealed condition and all notched-bar values are based on one S-N curve.

Relative Resistance to Corrosion

The four alloys prepared by the chlorine flux and carbon inoculation method have been checked in respect to their relative resistance to corrosion in a 3 per cent salt solution. The melts were poured into test bars which were heat treated and aged as described elsewhere.

The exposure was an alternate immersion type in which the regular test-bar specimens were placed in the bath for ½ min. and then withdrawn from this bath for 2 min. The 3 per cent salt solution was changed every 4 days and at the beginning of every new test. The loss in weight was determined for each of the alloys after an exposure to the bath for 1, 4, and 8 days.

The chemical analyses are listed in Table 7, and the corrosion results are graphically shown by Figs. 13, 14, 15 and 16 in which the loss in weight of the four different alloys is plotted against the iron content. Each point on these curves represents the average results obtained on four bars, excepting the ASTM-4 commercial bars from miscellaneous foundries. These points are based on one bar only.

Iron Content

Approximately 292 bars were tested in which the iron content was 0.022 per cent or less. A few additional bars with even higher iron content were also tested. As shown by Fig. 13, after one-day exposure ASTM-4 alloy appears to be the best, especially at iron contents above 0.012 per cent. AZ-91 is next, while A-8 and ASTM-17 alloys are similar and slightly inferior to the other two.

Figure 14 shows the results obtained after a 4-day exposure. As this figure shows, AZ-91 and ASTM-4 alloy are similar at least up to 0.020 per cent iron and are slightly superior to A-8, and ASTM-17 is slightly inferior to the other three. Figure 15 shows the results after an 8-day exposure to the alternate immersion in 3 per cent salt solution. Again, AZ-91 and ASTM-4 alloys are similar at least up to 0.009 per cent iron and are slightly the best, A-8 is next and ASTM-17 is slightly inferior.

Figure 16 shows a comparison of

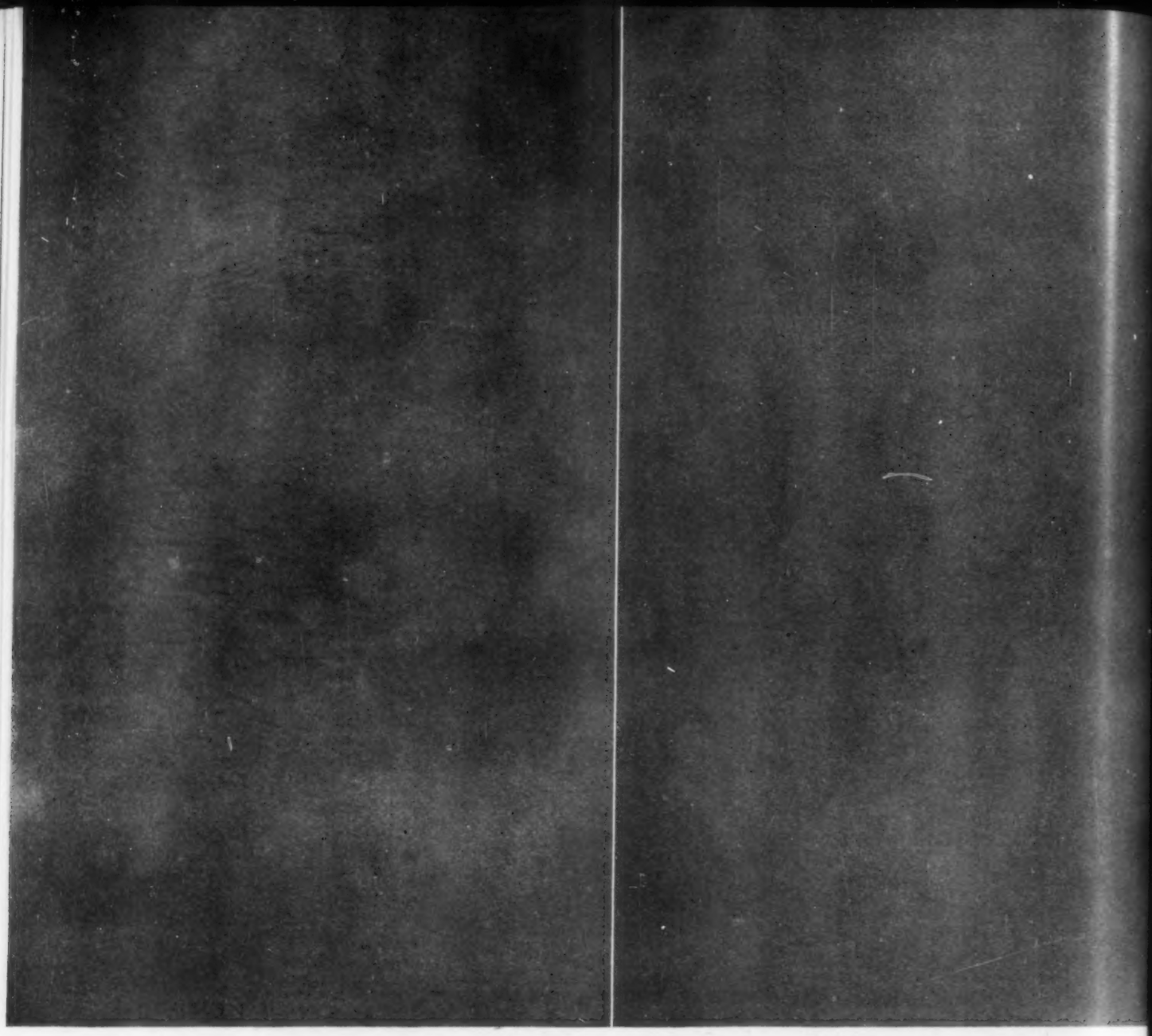

Fig. 6—A-8 alloy 3/16-in. plate test casting with 1-in. riser at gate end (bottom of radiograph). Wedge data — height of sound metal, 3 in.—grain size, 0.006-0.012 in. Metal cleaned with chlorine and treated with natural gas. This radiograph shows that the casting is practically free of microporosity, and also shows that this alloy is much less susceptible to the formation of microporosity than ASTM-4 alloy shown by the radiograph (Fig. 4).

Fig. 7—AZ-91 alloy 3/16-in. plate test casting with 1-in. riser at gate end (bottom of radiograph). Wedge data—height of sound metal, 2⅝-in.—grain size, 0.005 in. Metal cleaned with chlorine and treated with natural gas. The radiograph shows a very slight amount of microporosity in center of plate. Microporosity such as this is quite difficult to see on the fracture of heat-treated and aged castings, showing that the severity of the defect is very slight. A comparison of this figure with Figs. 4, 5, and 6 will show the effect of alloy composition on the occurrence of microporosity in this plate. Hence, the riser size and metal preparation are comparable for all four castings. It will be noted that ASTM-4 alloy is markedly more susceptible to microporosity than the other three alloys, ASTM-17, A-8, and AZ-91.

ASTM-4 alloy, the melts of which were prepared in two different ways. One method of melt preparation consisted of the usual commercial method of cleaning with a refining flux such as no. 310 and superheating. The second method of melt preparation consisted of cleaning and degassing with chlorine and obtaining grain refinement by carbon inoculation.

It will be noted from this set of curves that the metal which had been fluxed with chlorine and refined by carbon inoculation has somewhat higher resistance to corrosion in the alternate immersion 3 per cent salt solution than the same alloy prepared by the usual commercial method. This result is somewhat unexpected and probably should not be accepted without further verification. However, the superiority of the chlorine-fluxed metal might be attributed to the cleaner, sounder metal which is produced.

The results of the corrosion tests plotted in Figs. 13, 14, 15, and 16 are based on a considerable amount of comparative corrosion testing. There is some scatter in the results obtained, a characteristic of most tests of this kind.

To establish small differences among the various alloys would require a greatly augmented corrosion-testing program. Furthermore, the

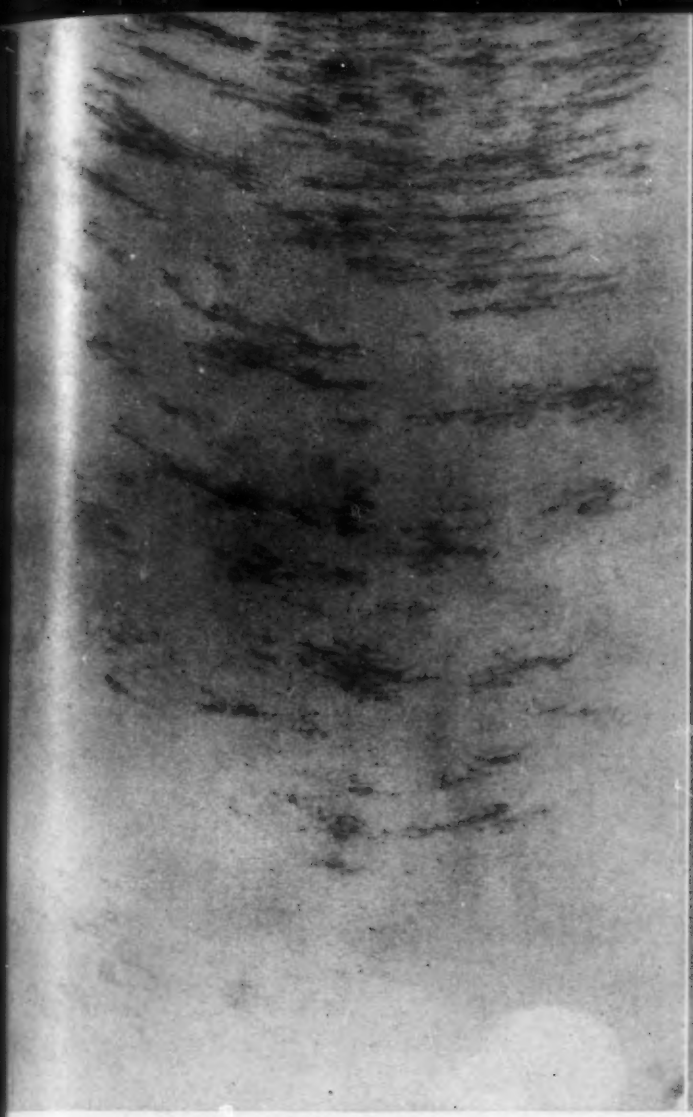

Fig. 8—ASTM-4 alloy ⅜-in. plate test casting, 1-in. riser at gate end (top). Wedge date—height of sound metal, 3½ in.—grain size, 0.006-0.007 in. Cleaned with chlorine-carbon tetrachloride mixture. Although metal has been degassed effectively and casting is well risered, considerable microporosity occurs, which is greatest adjacent to riser, indicating that unsoundness cannot be eliminated entirely by risering this casting. Figures 8, 9, 10 and 11 show same casting poured in the four alloys.

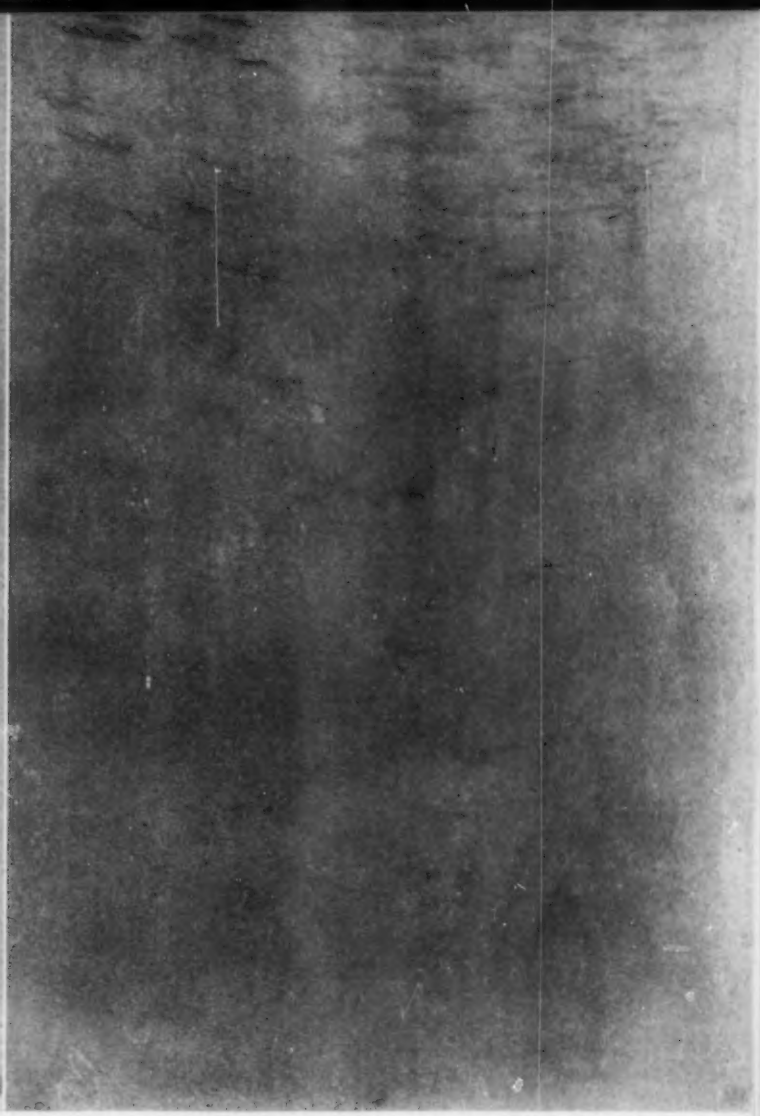

Fig. 9—A-8 alloy ⅜-in. plate test casting with 1-in. riser at gate end (top of radiograph). Wedge date—height of sound metal, 2½ in.—grain size, 0.004 in. Metal cleaned with chlorine and carbon tetrachloride mixture. Some microporosity occurs in this casting, particularly at the end adjacent to the riser. The amount of microporosity is considerably less than that shown by Fig. 8 and is greater than that shown by Figs. 10 and 11 of a similar casting poured in ASTM-17 and AZ-91 alloy, respectively.

determination of the comparative resistance to corrosion at low iron contents would require longer exposures and some of the scatter might be eliminated by complete chemical analysis of each bar. However, attempts to determine the cause of widely separated points by chemical analysis have not been generally successful up to this time.

Thus, the data do not permit precise conclusions regarding small differences among the alloys. However, on a practical basis it may be concluded from these data that at iron contents of less than 0.012 per cent and possibly less than 0.020 per cent, there is no substantial difference in the resistance to corrosion among the four alloys under test when exposed to alternate immersion in a 3 per cent salt solution.

Very limited data indicate that ASTM-4 is superior to the others at iron contents in excess of 0.012 per cent. ASTM-17 is unexpectedly inferior and this may be attributed to the lower manganese content of the bars tested. It is interesting to note that all four alloys have markedly higher resistance to corrosion when the iron content is low. In general, it may be stated that the resistance to corrosion of all four of the alloys is increased fivefold by decreasing the iron content from 0.015 to 0.005 per cent.

Relative Susceptibility to Hot Shortness

A hot-shortness test suggested by R. T. Wood, member of the N.D.R.C. Advisory Committee, when the work was first initiated, is shown by Fig. 17. The severity of the test can be adjusted by decreasing or increasing the distance "X" shown on this figure. The iron bar does not permit the casting to contract, and it tends to produce cracks on the inside corners adjacent to the risers.

This casting, therefore, produces the conditions necessary for hot cracking, namely, a high casting stress and a hot spot in the casting where cracking will occur. Since no fillets are used on the inside core, the cracking is confined to these corners. This is important because it limits the area that must be exam-

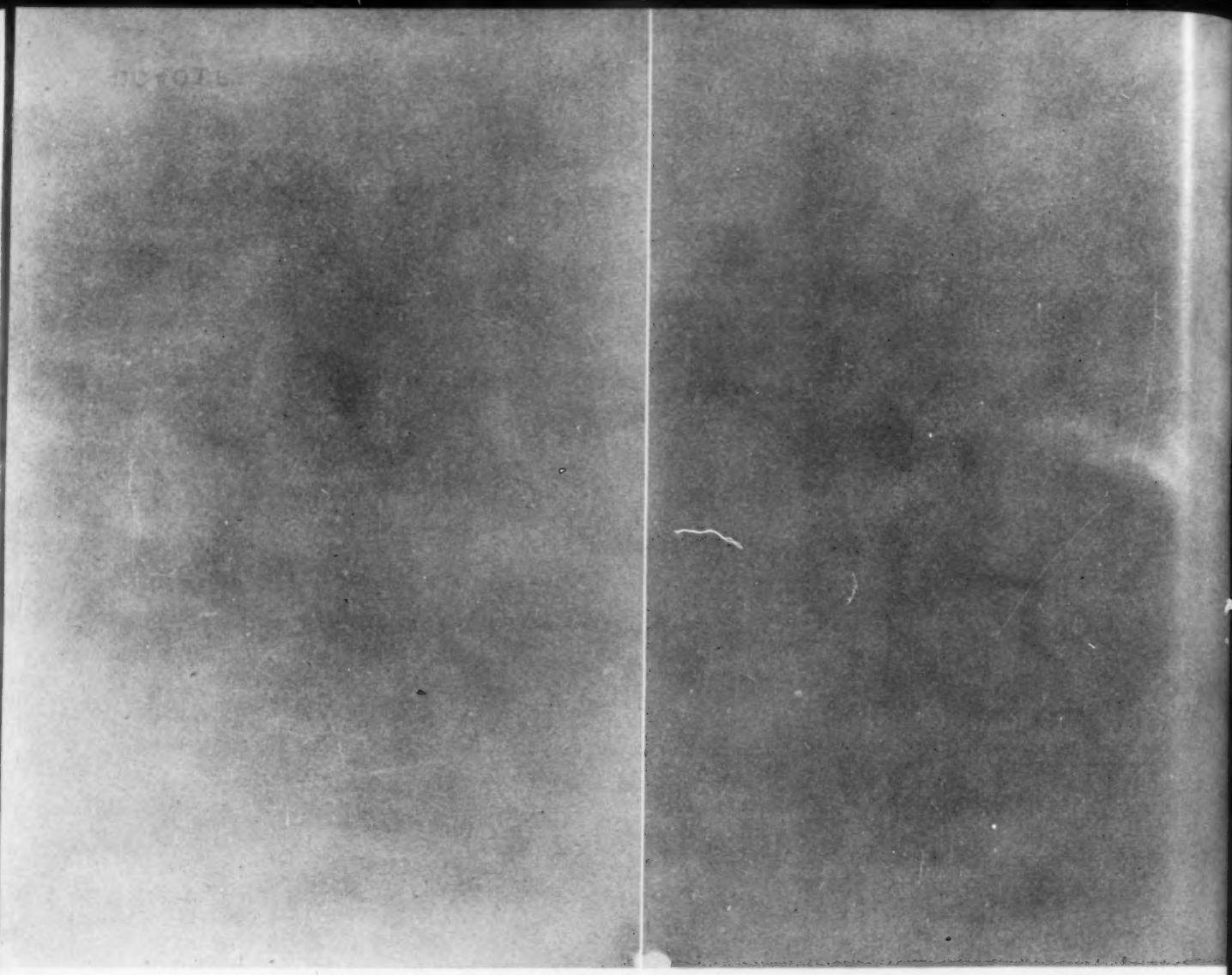

Fig. 10—ASTM-17 alloy ⅜-in. plate test casting with 1-in. riser at gate end (top of radiograph). Wedge data—height of sound metal, 2¾ in.—grain size, 0.006 in. Metal cleaned with chlorine and carbon tetrachloride mixture. This casting is substantially free of microporosity. Comparison with Figs. 8 and 9 shows that this alloy is considerably less susceptible to microporosity than ASTM-4 and somewhat less susceptible to microporosity than A-8. Comparison with Fig. 11 shows that it is about equivalent to AZ-91 alloy.

Fig. 11—AZ-91 alloy ⅜-in. plate test casting with 1-in. riser at gate end (top of radiograph). Wedge data—height of sound metal, 2¾ in.—grain size, 0.007-0.010 in. Metal cleaned with chlorine and carbon tetrachloride mixture. The casting is practically free from microporosity. By comparison with the preceding three photographs, AZ-91 composition is equivalent in its susceptibility to microporosity to ASTM-17 alloy, somewhat superior to A-8 composition, and markedly superior to ASTM-4 composition.

ined very carefully to detect hot cracks. This inspection must be carefully done, but the difficulties are greatly reduced if a fine facing sand is used in the corners.

The test is most severe and most likely to produce a hot crack in the casting when the distance "X" is a minimum and of the order of ⅛-in. As the distance "X" is increased, the severity of the test is decreased; when "X" equals 6 in., the severity of the test can be reduced still further by removing the steel bar.

The severity of the test can then be reduced still further by shortening the length of the arms, because as these arms are reduced, the sand offers less resistance to contraction of the casting. It is possible by means of this test to assign quantitative hot-crack numbers to various alloys or alloy conditions by assigning a number corresponding to definite positions or settings of the casting which just produce hot cracks.

The hot-crack number is arbitrarily defined as the value of "X" in inches. Thus, as the distance "X" is increased from ⅛-in. to 6 in. at which hot cracks just occur, the hot-crack number increases from ⅛ to 6. If the bar is removed, this setting is arbitrarily considered to be no. 7. For each inch removed from the length of the arms without the use of a steel bar, one is added to the hot-crack number. Thus, if the arms are reduced to 4 in., this setting being the point at which hot cracks just occur, the hot-crack number becomes 7 plus 2, or 9.

The hot-crack number of magnesium alloys varies between 1½ to 5 or more, depending upon the composition and the grain size. It has been found that the grain size probably has greater importance than alloy composition. When a grain size of 0.015 or 0.020 in. is obtained, most of the alloys are quite hot short. If, however, the alloys are all given a grain-refining treatment to produce representative fine-grained material, the various alloys can be compared.

When making a test, several molds are prepared in which the

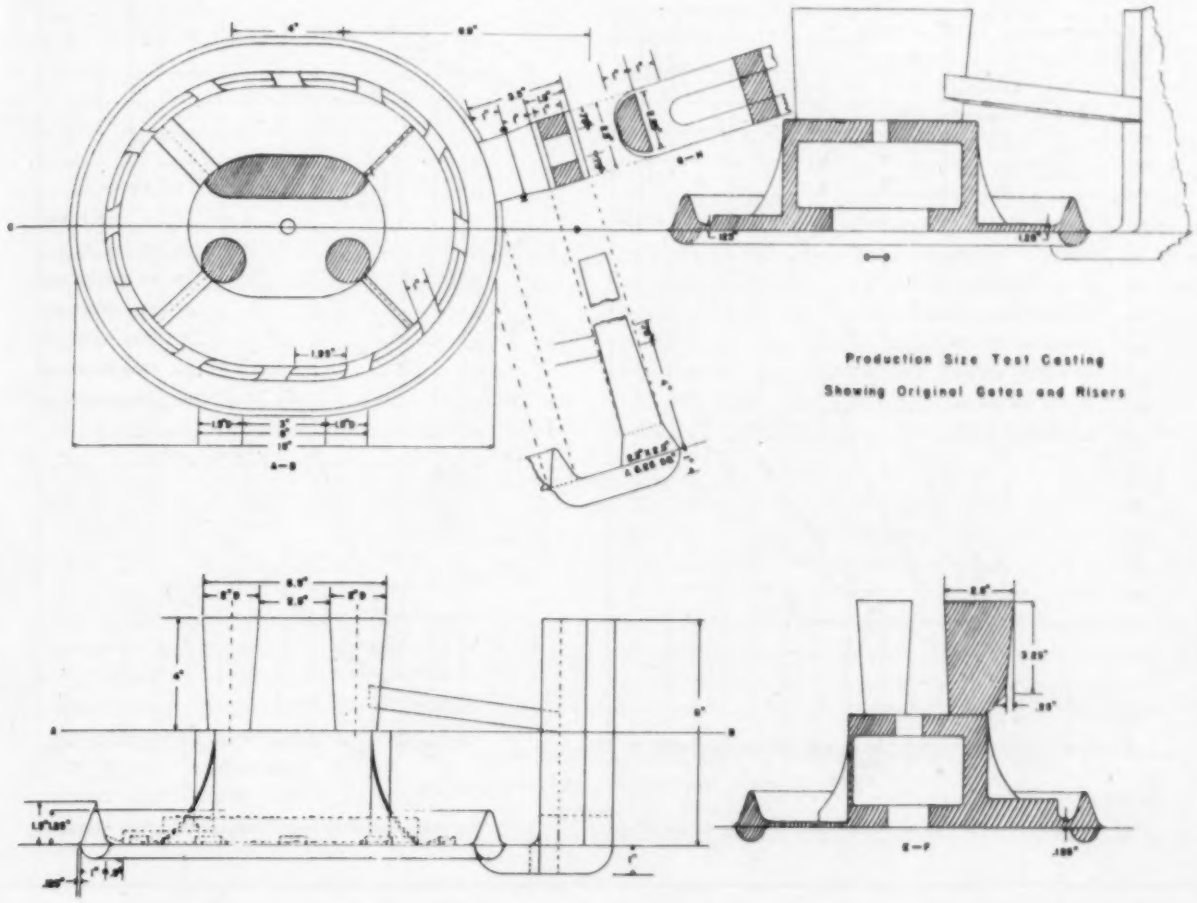

Fig. 12—Views of test casting, showing gates and risers, used to measure susceptibility of the four alloys to microporosity and leakage.

setting is varied progressively and in a systematic manner with the intention of having settings which will produce hot cracking and other settings which will not produce hot cracks. The number or setting midway between that which produces hot cracks and that which does not produce a hot crack is the hot-crack number.

Thus, if molds are set up in which the value of "X" is 2, 2½, 3, 3½, and 4 in., and if settings at which "X" equals 2 and 2½ crack, 3 produces a slight crack and 3½ does not crack, the hot-crack number lies between 3 and 3½. Consequently 3¼ is taken as a hot-crack number for this particular heat. The average results thus obtained on several heats of the four alloys which had the usual variations in grain size are shown by Table 8.

It will be noted by these data that ASTM-4 alloy is slightly more susceptible to hot cracking than the other three, while A-8, AZ-91, and ASTM-17 are so nearly alike in their susceptibility to hot cracking that no differences among them have been noted. The greater susceptibility of ASTM-4 alloy to hot cracking is in conformity with foundry experience.

Table 7

Analysis of Test Bars Used to Determine the Relative Resistance of Magnesium Alloys to Corrosion

	Alloy											
	ASTM-4			A-8			ASTM-17			AZ-91		
Element	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Al	6.4	5.8	6.1	8.7	8.0	8.4	9.7	9.0	9.3	10.3	9.9	10.1
Zn	3.0	2.6	2.8	0.63	0.41	0.56	2.3	2.0	2.2	0.72	0.39	0.62
Mn (1 day)	0.34	0.27	0.29	0.29	0.21	0.26	0.22	0.17	0.19	0.29	0.20	0.26
Mn (4 days)	0.29	0.27	0.285	0.29	0.28	0.285	0.20	0.17	0.18	0.29	0.27	0.285
Si	0.023	0.011	0.016	0.020	0.008	0.011	0.22	0.13	0.018	0.019	0.008	0.014
Cu	0.009	0.003	0.006	0.006	0.002	0.004	0.008	0.005	0.006	0.008	0.002	0.004
Ni	0.005	0.001	0.003	0.005	<0.001	0.002	0.003	<0.001	0.001	0.006	<0.001	0.002

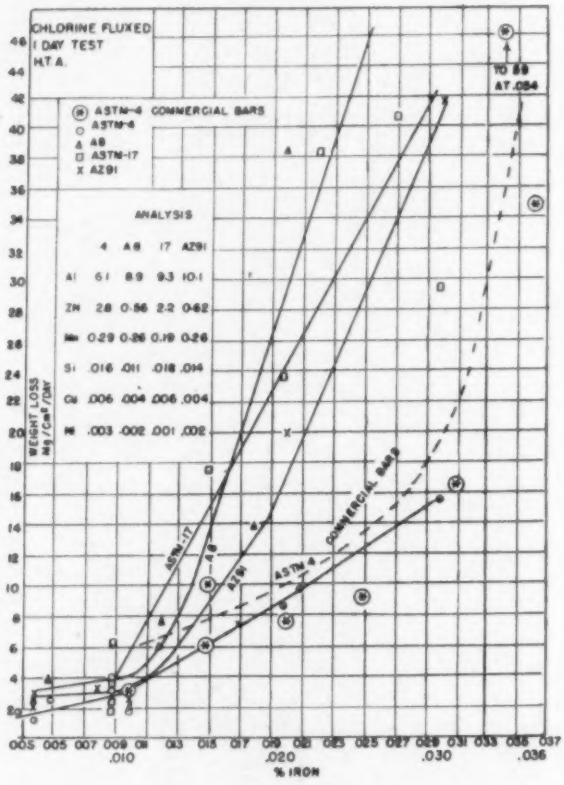

Fig. 13—Results of 1 day corrosion tests of magnesium alloys.

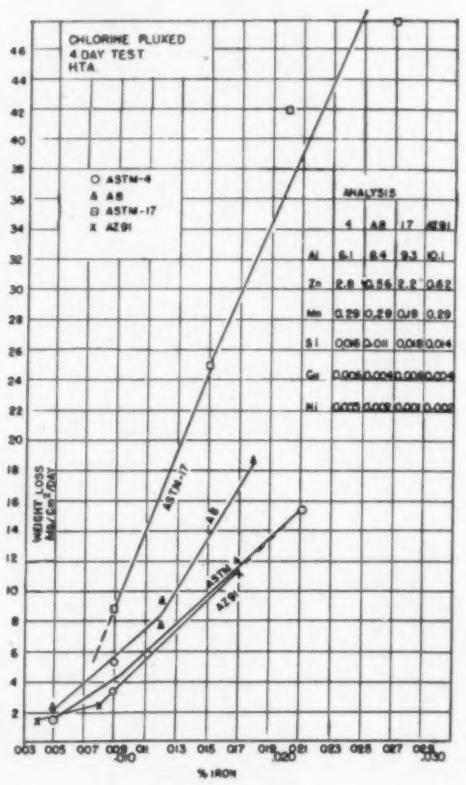

Fig. 14—Four-day tests, magnesium alloy corrosion.

Solidification Range and Amenability to Heat Treatment

It has been observed that there are considerable differences among the four alloys in their response and amenability to heat treatment. This arises largely through differences in the zinc content which the various alloys contain. The temperature at which solidification begins, that is, the liquidus temperature, is relatively easy to obtain.

Likewise, the univariant point at which the alloy-rich phase first begins to form can also be determined. However, the point at which solidification ends is not readily ascertained by means of cooling curves unless, perhaps, very sensitive experimental methods were employed. Some data have been obtained on the various alloys and these are listed in Table 9.

The univariant point, shown by Column 3 (Table 9), is a flexure in the cooling curve, and it probably corresponds to the line E_1E_3, Fig. 119, p. 88 in "Beck's Technology of Magnesium Alloys[8]." This point marks the beginning of the formation of the aluminum-rich phase. The liquid composition then follows along the line E_1E_3 in Fig. 119 of Beck's work.

Final solidification is at the lower temperature represented approximately by the minimum burning temperature, Column 4. The approximate minimum burning temperature shown by Column 4 is obtained by rapidly heating the alloy to various temperatures and then examining specimens to determine the point at which burning occurs.

The burning can be in one of two forms, either in the form of porosity similar to microporosity or fusion may have occurred. These two different forms of burning are illustrated, respectively, by the photomicrographs, Figs. 18 and 19. Hence, it is difficult to distinguish between microporosity and the porosity which results from burning. Therefore, the bars were also examined in the as-cast condition for comparison.

It is logical to assume that the minimum burning temperature is

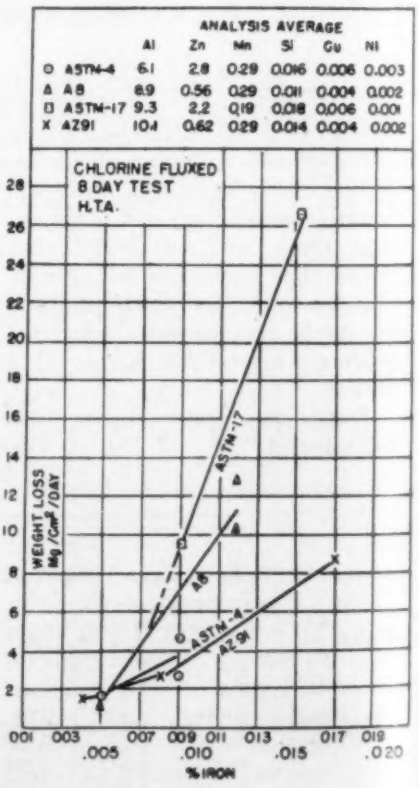

Fig. 15—Chart showing corrosion of magnesium alloys—8-day test.

Table 8

HOT-CRACK VALUES FOR THE FOUR CASTING ALLOYS

Alloy	Hot-Cracking Number[2]		
	Minimum[1]	Average[1]	Maximum[1]
ASTM-4	3¼	3⅛	>3¼
ASTM-17	<1	2⅜	2½
A-8	<1½	2	>3
AZ-91	2	2¼	>2¾

[1] *Minimum* indicates the lowest position number at which no cracks occurred in the several tests. *Average* indicates the average hot-cracking number which is the number midway between the setting at which cracking did occur and did not occur in a single test or series of molds poured from the same pot. *Maximum* indicates the highest position number at which cracking occurred in the several tests.
[2] The lower the minimum, average, and maximum values, the less susceptibility to hot cracking.

approximately the same as the temperature at which solidification ends. Owing to the possibility of a slight amount of diffusion, it is quite likely that the minimum burning temperature is slightly higher than the temperature at which solidification ends. Assuming, however, that the two temperatures are similar, Column 5 shows the solidification range of the four alloys.

The data shown in Table 9 are rather interesting because they show the fundamental reason for the major differences among the four alloys. The low-zinc alloys, A-8 and AZ-91, have a minimum burning temperature of approximately 800° F. Since this temperature is above the normal heat-treating temperature, it is apparent that these alloys are not apt to be damaged by too rapid heating during heat treatment.

A-8 alloy is, of course, more easily heat treated than AZ-91 because the lower alloy content requires less time at the solution heat-treating temperature. The two zinc alloys, ASTM-4 and ASTM-17, however, can very readily be damaged during the heat-treating operation if they are heated too fast above the minimum burning temperature. It is believed that these two alloys are damaged during heat treatment much more frequently than it is realized in industry.

ASTM-4 alloy is generally heat treated at 720 to 730° F., while ASTM-17 is normally heat treated at about 770 to 780° F. These temperatures are above the minimum burning temperature, and therefore burning is very apt to occur unless several hours are utilized to heat the charge from the minimum burning temperature to the normal heat-treating temperature.

Furthermore, it is not easy to obtain sufficient solution and diffusion of the alloy constituent at the minimum burning temperature or lower so that the castings can be heat treated at a higher temperature. Indeed, it has been found in the laboratory work that it is quite difficult to avoid some damage to these alloys even under laboratory conditions of heat treating.

The solidification range shown in Column 5 of Table 9 is also of considerable interest because it explains in part the differences in susceptibility of the alloys to microporosity. While there are many factors which determine the amount of distribution of microporosity in castings, there are two main factors which determine the susceptibility of a specific alloy composition to microporosity.

These two factors are solidification range and the amount of liquid which solidifies at the lowest solidification temperature, that is, the amount of eutectic liquid which solidified at the end. If the solidifi-

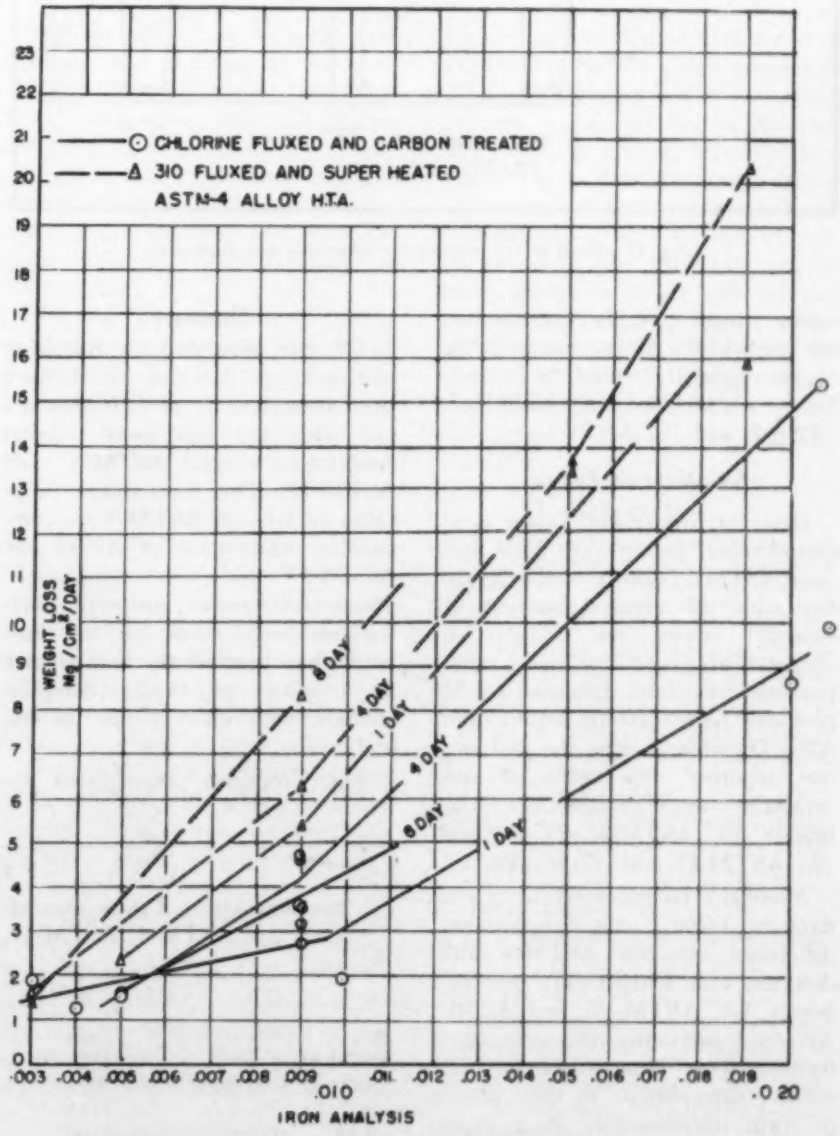
CHLORINE FLUXED AND CARBON TREATED
310 FLUXED AND SUPER HEATED
ASTM-4 ALLOY H.T.A.
WEIGHT LOSS Mg / Cm² / DAY
8 DAY
4 DAY
1 DAY
4 DAY
8 DAY
1 DAY
.003 .004 .005 .006 .007 .008 .009 .010 .011 .012 .013 .014 .015 .016 .017 .018 .019 .020
IRON ANALYSIS

Fig. 16—Comparison of ASTM-4 alloy melts in corrosion tests.

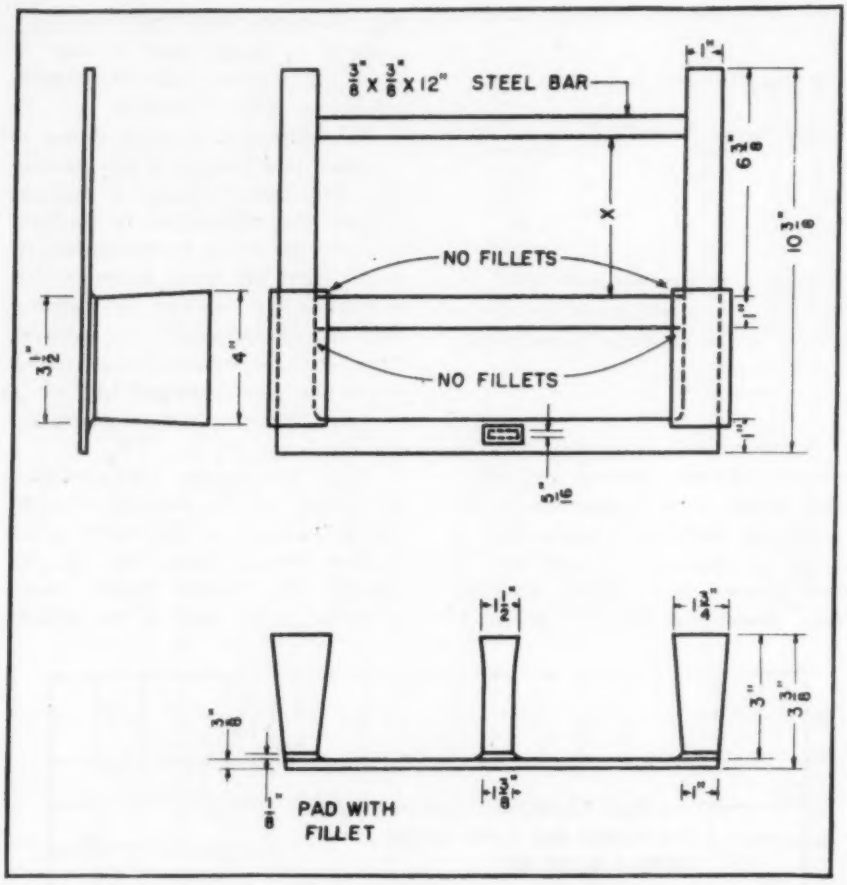

Fig. 17—Views of test casting for measuring hot shortness.

cation range were the only factor, the order of decreasing susceptibility to microporosity would be as follows: (1) ASTM-4, (2) ASTM-17, (3) A-8, and (4) AZ-91.

Solidification Factor

However, the second factor is of considerable importance also, and since ASTM-17 alloy probably solidifies with the greatest amount of eutectic liquid, its position is changed from no. 2 to no. 4 comparable with AZ-91. Likewise, AZ-91 produces more eutectic liquid than A-8. Therefore, taking the two factors together, the order of susceptibility to microporosity is as follows: (1) ASTM-4, (2) A-8, and (3) ASTM-17 and AZ-91 alloys.

As might be expected from the data in Table 8, there is a large difference between ASTM-4 and A-8, and only a slight difference between A-8, ASTM-17, and AZ-91. As noted previously, this is in conformity with observation on the relative susceptibility of these alloys to form microporosity in a given casting.

Summary

The two most popular European casting alloys, A-8 and AZ-91, have been compared in considerable detail with the two most popular American alloys, ASTM-4 and ASTM-17. The mechanical properties of A-8 and ASTM-4 are comparable, while those of AZ-91 and ASTM-17 are also comparable. These mechanical property comparisons were made on test bars which had been ideally heat treated to produce practically complete solution with only a trace or less of burning.

The properties investigated are tensile strength, yield strength, per cent elongation, per cent reduction in area, resistance to failure by tensile and Charpy impact, and endurance limit. There is some indication that with these ideally heat-treated materials, ASTM-17 is slightly superior to the others in the heat-treated and aged condition.

Corrosion Resistance

The resistance to corrosion of the four alloys has been investigated by alternate immersion in the 3 per cent salt solution. ASTM-17 is slightly inferior to the other three alloys probably because of the lower manganese content of the bars investigated, but in general it is concluded that within the limits indicated in the following, the resistance of the four alloys to corrosion in this medium is approximately equivalent.

This is certainly true if the iron content is less than 0.012 per cent and possibly true if the iron content is less than 0.020 per cent, but probably not true if the iron content is in excess of 0.020 per cent.

As to the susceptibility of the four alloys to hot cracking, the grain size is a greater factor in determining the susceptibility to hot shortness than alloy composition. However, with melts which have been subjected to a grain-refining treatment, ASTM-4 is slightly more susceptible to hot shortness than are the other three alloys.

The susceptibility of the four alloys to the formation of microporosity in several different castings has been determined. In sections 3/16 and 3/8 in. thick, which are representative of the great majority of section thicknesses of commercial castings, ASTM-4 alloy is markedly more susceptible to microporosity than the other three alloys. A-8 composition is slightly more

Table 9

SOLIDIFICATION RANGE AND MINIMUM BURNING TEMPERATURE OF ASTM-4, ASTM-17, A-8, AND AZ-91 ALLOYS

1	2	3	4	5
	Temperature, °F.			
Alloy	*Liquidus*	*Univariant Point*	*Burning (approx. min.)*	*Solidification Range (column 2 minus column 4)*
ASTM-4	1125	750	650	475
ASTM-17	1095	800	750	345
A-8	1115	810	800	315
AZ-91	1100	810	800	300

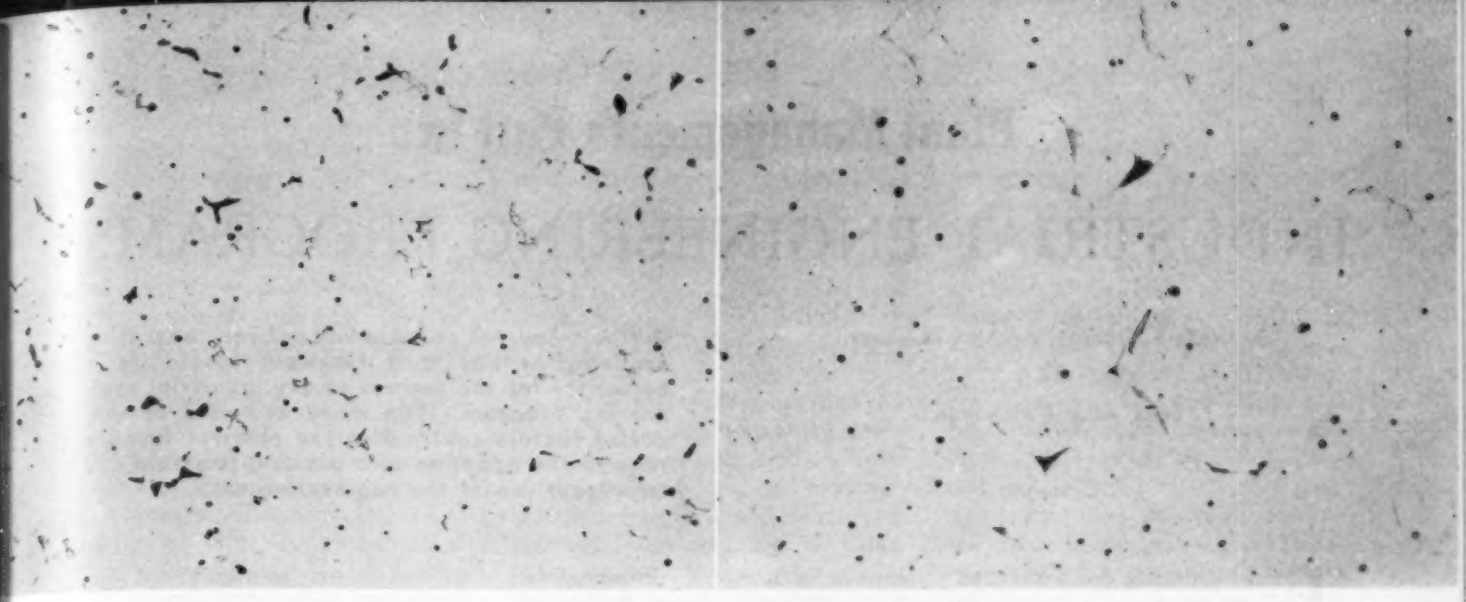

Fig. 18 (Left)—Photograph at 100X, showing ASTM-4 alloy held 2 hr. at 610° F., heated from 610 to 720° F. in 5 min. Comparison with the as-cast bars shows that the porosity is caused by burning. Fig. 19 (Right)—Photograph at 100X, showing the fusion type of burning. The alloy is ASTM-17 heat treated 16 hr. at 740° F., after which similar specimens showed no burning. This specimen was then heated from 740 to 770° F. in 5 min., which treatment, in this instance, caused the fusion type of burning.

susceptible to microporosity than ASTM-17 or AZ-91 composition, but much superior to the ASTM-4 composition.

In conformity with these findings, it also appears from limited data that ASTM-4 castings are much more susceptible to leakage than the other three compositions. Since leakage in magnesium castings is primarily produced by microporosity, it is logical that the susceptibility to leakage should parallel the susceptibility to microporosity.

No substantial difference has been noted among the four alloys in respect to their amenability to a degassing treatment or to a grain-refining treatment.

Heat Treatment Response

The amenability and response of the four alloys to heat treatment have been investigated in considerable detail. The minimum burning temperature of the low-zinc alloys, A-8 and AZ-91, is about 800° F., a temperature which is above the normal solution heat-treating temperature.

ASTM-4 alloy will burn if rapidly heated to temperature above 650° F., a temperature which is about 80° F. below the normal solution heat-treating temperature. ASTM-17 will burn if it is rapidly heated to a temperature above 740° F., a temperature which is about 30° F. below the normal solution heat-treating temperature.

It has been found quite difficult to heat treat the two high-zinc alloys, ASTM-4 and ASTM-17, at a sufficiently slow rate above the minimum burning temperature to avoid burning, or to preheat them below the minimum burning temperature on a practical basis to alleviate the difficulties. It is believed that these two alloys are damaged in commercial heat treating much more frequently than is generally realized, because the results of the burning are generally quite similar to the defect known as microporosity.

The possibility that calcium, commonly used by some foundries, might decrease these difficulties has not been investigated. Alloys of the A-8 and AZ-91 compositions are the most readily and reliably heat treated, the A-8 composition, of course, being easier to heat treat than the AZ-91 composition because of its lower alloy content which requires a shorter time at the solution heat-treating temperature. ASTM-17 is more difficult to heat treat than ASTM-4 because the higher alloy content requires a much longer time to obtain proper solution.

In general, only slight advantages of the two high-zinc alloys, ASTM-4 and ASTM-17, over the two low-zinc alloys could be found, but they are subject to very serious disadvantages as compared with the low-zinc alloys. It is believed, therefore, that it is only a matter of time before the present commercial high-zinc alloys will be abandoned in the United States as they are being avoided or abandoned in Europe.

Acknowledgment

To the Office of Production Research and Development of the War Production Board, which sponsored the work described in this paper and granted permission for its publication, to the Office of Scientific Research and Development, under whose guidance this work was done, to members of the Advisory Committee on Project NRC-546, and to many members of the staff of the Battelle Memorial Institute, especially Messrs. C. H. Lorig, C. T. Greenidge, and A. R. Elsea for their valued assistance, the authors gratefully express their thanks and appreciation.

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Plant Management's Part In

INDUSTRIAL ENGINEERING PROGRAMS

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Chicago

● ***Whole-hearted cooperation between operating organization and staff technical specialists is necessary for the success of any industrial engineering program. The many new and complicating factors confronting the postwar foundry require the adoption of a planned program and intelligent use of the engineering staff.***

THE borderline band between profit and loss is but one cent wide. The boundary between success and failure in business is, perhaps, no wider. Inevitably, the success of a company is reflected in its ability to make a profit.

There is no royal road to insure this objective, but in the *intelligent* use of industrial engineering, many large companies and many small companies have found the way to produce at 5, 10, or 15 per cent less cost. However, the cold fact remains that many other firms which turn to engineering management fail to make the program click.

What is Industrial Engineering? The scope of industrial engineering is broad and varied. There is no universally accepted definition for it. It means, to some, time study engineering, and to others, wage incentives, standards, layout, methods, cost control, production planning, or even the whole field of scientific management. One defines it best by listing the work or functions which it is desired to embrace and then establishing a staff to carry on the designated work.

Just as the military has staff and line departments, so too should industry. In the foundry the *line* was from president on down to operating manager, superintendent, general foreman, foreman, and gang boss; they aid in holding the line.

The staff departments, when set up as such, generally are the metallurgical or the laboratory, the personnel, the production control, the plant engineering, and sometimes the industrial engineering.

Old-line foundry management did not believe in having staff functions separated from line control. The superintendent ran everything. The head melter did what metallurgy the shop required. The foundry foreman ran the scheduling from an envelope in his hip pocket.

He or his assistant foreman did their own hiring and firing. If they chose to have piece rates, they set them from experience. The master mechanic did whatever engineering or construction jobs there were to be done.

With the growth of multi-plant

Complete understanding is necessary for the success of industrial programs.

companies came staff management. World War I and the booming Twenties saw many foundries setting up staff departments. Some succeeded—many failed. There were frequent skirmishes between staff and line men for authority. The staff man was an outsider and when, as too often happened, his work was passively resisted by the old timers' clique, it fell flatter than a pancake.

Industry Needs Engineering Control. Management is no longer the simple matter of making and selling castings at 20 per cent over cost that it once was. New laws have complicated matters. Labor legislation, the advent of the mass union organizations, the rising tide of taxes of all varieties, the specifications for alloyed metals, the demand for x-ray and magnetic particle examinations for defects, and the mechanization of the industry are but a few reasons why a plant or company of any size today has been forced to come to staff departments manned by technical specialists.

Sheer tragedy lies in a foundry's failure to make intelligent use of the engineering technicians it employs. C. T. Kettering has likened the hiring of a research man into an old-line organization to the tossing of Daniel into a den of lions. The Lord saved Daniel, but most of the staff men in foundries, unfortunately, are not possessed of Daniel's religious fervor or indispensability. To make a bad pun, they are devoured by the *lines* before they get started.

Staff and Line Cooperation

This is all very expensive on the industry. There is so much that the technical man can do. There is so much to be done to keep a foundry in a competitive position. A way must be found to get the staff on a proper footing so that the friendly cooperation of the line will assure success of the whole profit control program.

How Much Industrial Engineering for the Foundry? The foundry program of industrial engineering should be threefold:

1. There is the program of *preparation.* The equipment, the layout, and the methods all must be studied. Greater production per man hour with less physical effort and in better surroundings must be achieved for every operation.

Engineering analyses when combined with the practical experience of the man running the operations can do wonders, whether the work be of a production or jobbing type.

2. There is the *standards* program. Standards call for standardization of every operation. Standard practice data for speeds, feeds, number of jolts, temperatures, sand mixtures, baking times, gating and risering, air pressures, flask sizes, use of chills, finish and inspection requirements are but a few of the items that standardization can help.

Operating Standards

If the foundry management does not provide these operating standards for its line supervisors, it can never hope to produce uniform quality or to keep defective work under control. If one way is better than another, management should see that every foreman knows and teaches that method.

After the right layout and method are devised, motion study comes in to further simplify the work or human effort. The one best way must be set as the standard, and the proper time for it must be established either by time study or by time-studied standard data and figures.

Wage incentives are needed, because a good man working hard can exceed a fair standard by 20 to 30 per cent and deserves a 20 to 30 per cent reward for such output.

Cost standards are another part of the standards program. Good management should be able to tell its supervisors the proper cost for any operation. If it cannot do so, it cannot fairly tell when a foreman is making a real success of his job.

Cost standards should be established to provide a comparison for dollar spent for labor, material, and expense under all conditions and for all classes of work.

3. There is the program of *cost control.* Good standards, adequate incentive plans, and proper cost control budgets provide management with tools for knowing where they are going profit-wise. Labor needs can be forecast based on tomorrow's schedule.

Actual labor used can be compared to standard for yesterday's performance and for last week's. Labor costs and all other elements of expense can be compared weekly or monthly as preferred.

The line supervisor must be the manager of his department. He spends money every time he signs a labor ticket or a material requisition. He must know what he spends and how this total stacks up against what he should be spending. Unless management can tell him this, they cannot expect him to contribute intelligently to the profits program.

Every management should be able to estimate its cost before it takes an order. The easiest and quickest way to go broke is to sell *at* or *under* the competitor's price without knowing if the price is right or if one can produce as economically as can his competitior. The scores of foundries which go broke every year attest to the danger of this sales-pricing method.

Cost Accounting System

Accurate estimating of expected costs before a bid or price is ever made is the answer. The sound foundry estimate should come as a combination of careful planning for the equipment and the operations, coupled with the determination of the probable output per man hour, sound prediction of scrap losses, plus proper application of metal costs and overheads for departments and for plant-wide expense.

The industrial engineer should steer every estimate and compile it, but it must meet with the approval of the planning group and of the superintendent.

Good profit control demands an accounting system which makes profit figures readily available during a run as well as at its conclusion. The industrial engineer should have access to all actual cost data and be able to turn out comparative cost figures that parallel his estimate at any time the management, the sales department, or works manager require information as to the status of a job or order.

A foundry seldom makes money by accident. Eternal vigilance and constant cost comparisons with the standards or the estimates are powerful elements of profit control.

How to Correlate Staff and Line Operations. To attempt to jam a

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Job Evaluation and Time Study Committee of A.F.A.

time study or wage incentive program down a foundry foreman's throat is futile. Passive resistance on his part is such a strong and yet so subtle a weapon that he can render the best of engineering programs valueless.

Unless the foreman can understand the program and can appreciate its need, one should either give up the program or change the foreman. This is harsh advice but is seriously given and with an idea to economy of time and expense.

Definitions help. Delineation of authority between staff and foreman in a single-plant company, or between general office staff and the works managers in a multi-plant company is highly essential. The foundry manager has a right to feel that he is running every man in his plant and that all plant staff men are his own staff.

He is, therefore, vitally concerned with programs, plans, and installations on which his staff work. He wants no cut and dried incentive plans or control media foisted on his organization until he can review and test them in the light of what is sound or beneficial for his men and his foundry's operations.

Planning the Program

Best way, then, to begin any staff program is to plan it out all very carefully with the men who must help make it work. If in a single-plant company, the operating head, the plant manager, the superintendent, the controller, the personnel man, and the industrial engineer or staff head all should participate.

If in a multi-plant company, the operating vice-president, the controller, the personnel director, the chief industrial engineer, and the works managers of all plants concerned should take part.

Plans under consideration should be considered and tested from numerous angles. How would they affect the workers and the foreman; what new records would be required; what of production; what about costs of installation and operation; how about the profit angle?

Sound planning of this nature takes time. Any foundry can improve its employee relations if it studies and analyzes its whole wage administration program with an eye to coming abreast of the times.

Necessary, or at least extremely helpful, are frank and open statements of policy, the preparation of an employees' manual, the adoption of an evaluated wage schedule, the issuance of a clear-cut statement or explanation of any new or old incentive plan, and the undertaking of broad educational or training plans to acquaint both supervision and workers alike with the objectives of management.

This sounds like a big mouthful, but the preparation and explanation of such a broad program will force management to correct inconsistencies in operations and policies, and will return healthy dividends. Best of all, the work bridges the heretofore uncrossable gulf between line and staff, sets them to pursuing a common goal, with a mutual respect each for the other.

From understanding comes cooperation and cooperation points the way to success.

Fig. 1—Sand under the microscope. A magnesium sand at 40x. Top—New sand. Bottom—Reclaimed sand.

SAND RECLAMATION

By Ronald Webster and A. C. Den Breejen,
Hydro-Blast Corp.,
Chicago

• Improving castings quality by the use of reclaimed sand. Within certain limits, the sand reclamation process in itself controls sand grain size and distribution, cleanliness, moisture content and temperature. Sand storage and waste disposal problems are solved in many instances.

THE dollar interest is probably not the dominant human motive, but it is an important one and a very good measure of the practicability of any reform or of any good intention. The dollar stands as a constant critic over our acts and limits them.

If the systems for the recovery of sand now wasted from foundries could not show a dollar saving, it would be very hard to bring them into use, even if the results were superior to results previously obtained. It is our primary contention that the quality of castings which can be produced in a foundry using a reclaimed sand will be better in most instances and on the average than can be produced from new sand. However, the money saving cannot be overlooked; it is there.

The statement concerning the quality of castings will be less startling when it is apparent that a sand reclamation system is a compulsory sand control, with all that that implies. It can and will give control, within certain limits, of the grain size and distribution, cleanliness, moisture content and even the temperature of the sand. Because one starts with a known quality which can be the same every time, refinements in procedure in amounts of bond, moisture, mulling time, etc., will have meaning.

Waste Sand Economic Aspects

This preface concerns itself with the economic aspects of sand reclamation systems, and begins with the point that *sand is the most considerable item of waste in most foundries.* This waste comprises a great deal more than the cost of the new sand. Whenever new sand is bought, an equivalent amount of waste sand must be hauled away or the foundry will fill up. Disposal charges must, therefore, be added.

In addition, there are unloading and other handling charges, but the major item is storage space for the winter months in those regions where it can neither be delivered or stored outside during a part of the year. All of this must be added to the cost of the sand.

It is now practicable to wash, scrub, classify and dry foundry sands of most kinds for somewhere between 50 cents and one dollar a ton, including the following items: power, water, fuel, direct labor and maintenance with its labor. The precise process and the precise equipment necessary for any given plant and process can be determined only by a study of the individual foundry, although foundries fall into several definite groups.

In very small foundries, the capital cost of equipment to accomplish this purpose will be too great; also, labor costs increase sharply with decreased volume. For example, one man can operate a system delivering 15 tons an hour about as easily as he can operate a system delivering 5 tons an hour or, for that

matter, one ton of sand per hour.

Not only the very small foundry but certain other types of foundries are not in a position to consider sand reclamation systems. Typical of these are many foundries in England where the material used in molding is not sand but chamotte or loam, or in this country, foundries using cement, which latter presents its own particular difficulties.

Sand Quality

Certain other foundries cannot well use a reclamation system because of the quality of the sand they now employ. These foundries have found it economical in the past to use a relatively cheap sand available locally, even where it is weak and the loss is very great.

This condition obtains most conspicuously in the Pacific Coast area, where very few really good sand deposits have been found. In many of these foundries, a reclamation system will justify a change of sand and of sand practice from local sand with a low initial cost to a better sand obtained even at a much greater cost from a distance, or the use of a high grade local sand if it is available.

Granted a recovery of 85 per cent, which is quite possible with a good sand of the proper grain shape, it will be cheaper to start with a sand at $10.00 a ton than with an unsatisfactory sand at $2.00, and better castings will result. This, in a way, frees the foundryman from the purchasing agent and permits him to make a technical improvement at a saving.

Special Materials

In some exaggerated cases, reclamation systems will permit the use of special materials needed to accomplish some particularly desirable result. From the dollar point of view, if it were desirable technically, it would be possible to use zirconium silicate in large quantities instead of silica sand, provided that a recovery of 90 per cent could be obtained. This, of course, would hold only in special cases where the supposed advantages of a very high sintering point would warrant the use of the material. If is merely pointed out that economically such a step would be possible, if it were desirable.

The question of disposal of waste sand deserves further elaboration. Many foundries were built on what was apparently waste land, quite often in swamps, and the waste material was used as fill. Certain long-sighted foundry executives selected sites which later became real estate developments. The swamps do not last forever and the real estate developments become realities, and the problem arises sooner or later of hauling sand a greater distance and paying a premium for the privilege of dumping it.

In some cases, also, the sand used to be dumped into rivers, a practice which is not looked upon with any favor by local communities. A great many foundries are, therefore, faced at this moment with increased disposal costs running from $1 to $2 or $3 a ton.

It might also be pointed out here that the scrap sand usually contains a considerable amount of iron. Under war conditions, this loss of metal has been greatly reduced by the amount which could be salvaged as a by-product of the sand reclamation system, and is another item on the profit side.

Sand Storage

Storage space is an interesting by-product of a sand reclamation system. Assuming an average use in steel foundries of one ton of new sand for every ton of castings produced, and regarding the transportation season as closed for 4 months of the year, it is easy to arrive at a minimum safe storage capacity for a foundry of any size. Bins cost money and take up space, and to be useful require a roof.

A sand system with a yield of 85 per cent will eliminate the need for 85 per cent of this storage space. In several instances, the cost of bins with their handling system was not greatly less than the cost of a system to reclaim the sand.

Outside storage is a practical impossibility in a well-conducted foundry. Some foundries have been forced to store the sand outside, but few like to do so. They anticipate difficulties whenever they have to use sand from an outside pile unless they have equipment to thaw and dry it.

Most foundrymen have also had experience with wet cars and with frozen cars. It is common practice in many foundries to dry all core sand in any event, thus gaining one of the advantages of a reclamation system, namely, a controlled moisture content. Drying sand in this method is not as economical as it could be. Some cars are much wetter than others, and drying systems have to be overdesigned to meet the extreme conditions.

Drying Core Sand

It is not always easy to change the setting of burners when relatively dry sand is received, and the sand is overheated and retains its heat for a long period in the storage bins. This will have a particularly bad effect in large corerooms where cores are made on a production line. The temperature of the sand is important in the control of moisture and, under some conditions, may result ultimately in stickiness in core boxes.

In the preparation of this paper, which does not go into the economies of sand reclamation, data were obtained from the results in seven or eight foundries which have used this system over many years and processed many thousands of tons of sand; and from a pilot plant having a capacity of between one and three tons per hour, dependent upon the particular problems to be solved. Sand from more than 100 foundries has been run and examined in this pilot plant. Most of the runs were based on 5-ton lots of waste sand.

The sand has been collected from many sources—floor sweepings, core butts, shakeout material. In many cases, the reclaimed sand was returned to the foundry and used in cores or in facing material with satisfactory results. Processing of lots of less than 5 tons is not considered significant. Laboratory tests in themselves mean nothing whatever. The answer is good castings.

Sand Reclamation

Definition—By sand reclamation is meant the processing of spent foundry sand, normally wasted, in such a manner that it may be used in place of new sand without substantially changing current practice.

It is necessary to make this definition clear because the term has been applied to a variety of processes in which this object was not attained and, perhaps, not sought. In this paper, the word "recovery" will mean the percentage of treated sand, suitable for use instead of new sand, which is yielded from any specific sand reclamation system.

The subject matter is of almost

GRAY IRON SAND RECLAMATION

(All photographs at 15x; enlarged to approximately 30x)

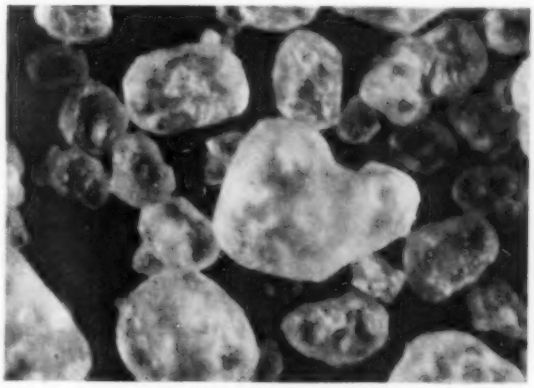


Fig. 5—New sand.

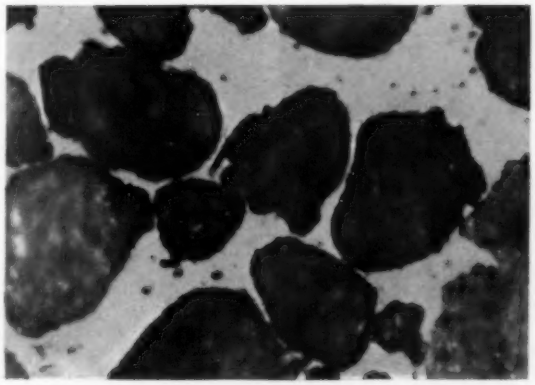


Fig. 6—Discard sand (used).

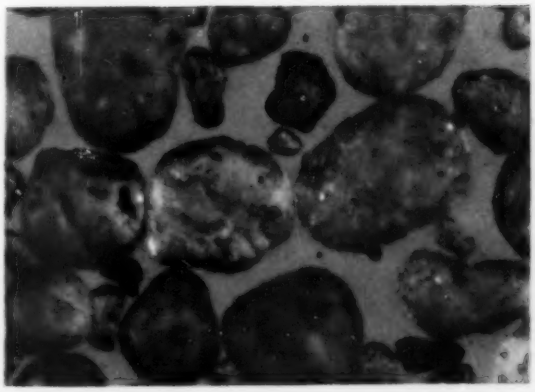


Fig. 7—Sand as reclaimed.

NON-FERROUS SAND RECLAMATION

(All photographs at 15x; enlarged to approximately 30x)

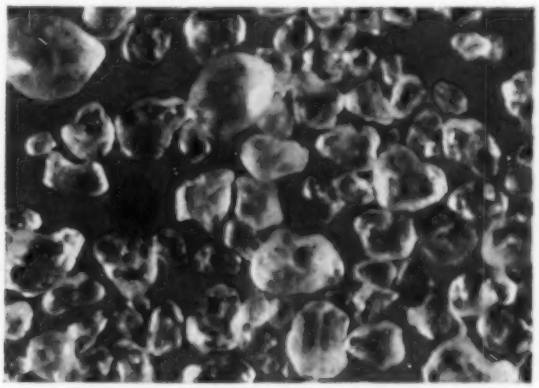


Fig. 8—New magnesium sand.

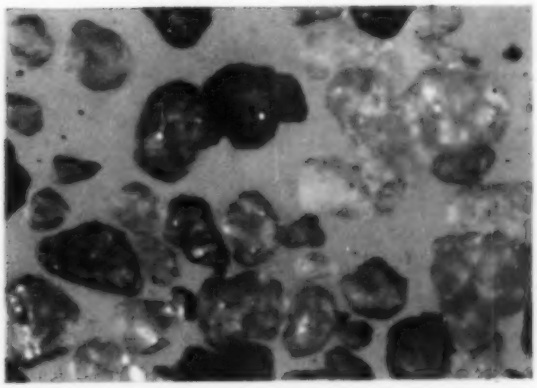


Fig. 9—Discard magnesium sand (used).

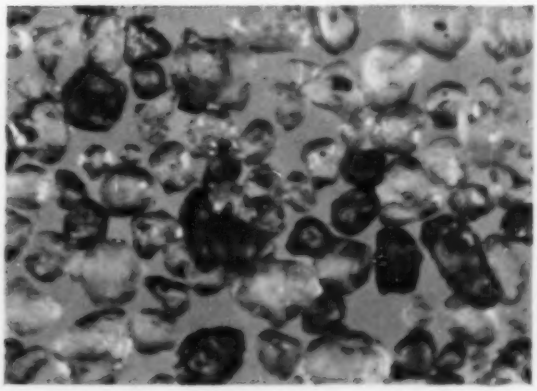


Fig. 10—Magnesium sand as reclaimed.

STEEL SAND RECLAMATION

(All photographs at 15x; enlarged to approximately 30x)

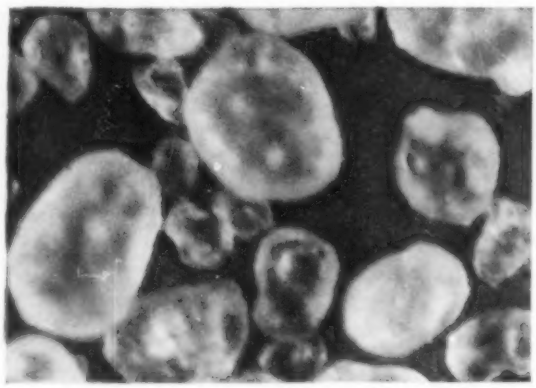


Fig. 11—New sand.

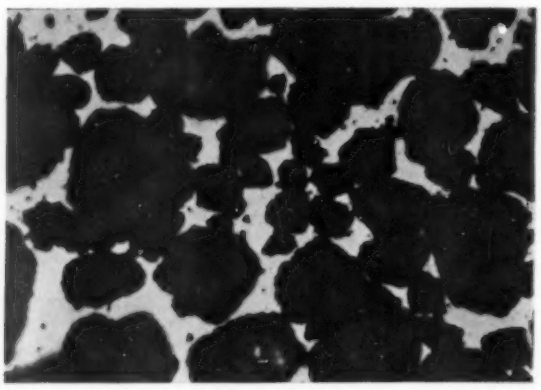


Fig. 12—Discard sand (used).

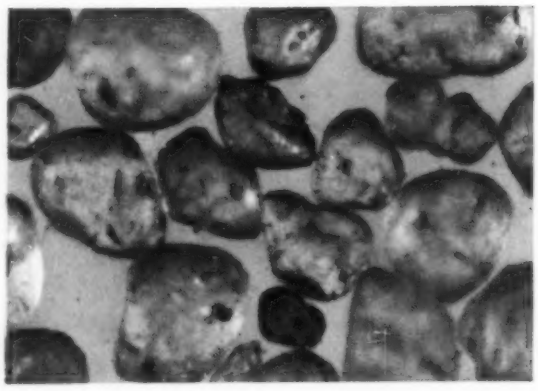


Fig. 13—Sand as reclaimed.

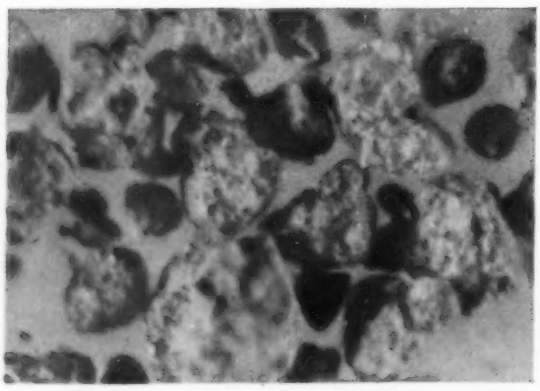


Fig. 14—Used sand ignited to show residue.

These color plates of sand were not prepared with the intention of showing true color but rather to escape certain limitations imposed by black-and-white photographs. Most of the bluish cast, even in the new sand, is misleading, as comparison with the black-and-white photographs will show. Color slides of sand projected on the screen are somewhat more satisfactory.

Typical sands for steel, gray iron and light metals were selected for 5-ton runs in a 3-ton-per-hour pilot plant. In one case (Fig. 14), the spent sand was ignited to show in an exaggerated manner the product resulting from burning a heavily bonded sand. This does not represent the product of any well-engineered thermal process. Pastel shades of color from light metal sands (Fig. 9) are the result of dyeing cores with analine dyes.

no interest to foundries using naturally bonded sands, but the practice in such foundries of adding new washed sand or relatively clean spent core sand to keep up the permeability of the naturally bonded molding sand serves to bring out another point, and may better define the objects of this paper.

In several foundries visited, some official has flatly asserted that they already recover their core sand. Upon further inquiry it developed that they were permitting a portion of their used core sand, or all of it, to mix with the molding sand to maintain its permeability and, at the same time, adding bond to keep its strength. In such cases, of course, they were buying new sand for use in cores and in facings, and were wasting tonnage roughly equivalent to the new sand which was purchased.

Core Sand Production

In one foundry visited 5 or 6 years ago, there was no apparent waste, but the foundry superintendent pointed out that the floor at one end of the foundry was 4 or 5 ft. higher than it had been 2 or 3 years before. These foundries are, of course, making molding sand out of core sand. However, they are not reclaiming core sand in the meaning of this paper.

Whatever the practice, core sand is almost invariably a new sand relatively free from bond, sometimes mixed with used sand in small proportions and frequently with the additions of material like silica flour, oil, small percentages of fire clay and some material such as cereal flour. The point is that for cores and some facings new sand is, by more or less common consent, required. It is the production of this sand, or its equivalent, from waste materials to which the various processes of sand reclamation are pointed.

Nature of Sand—To accomplish the purpose of producing a good core sand from spent core sand or from molding sand, it is necessary to examine the characteristics of individual sands and even individual sand grains at some length before attempting production.

A.F.A. standards classify sands into angular, subangular and round grains. Inasmuch as these sands have been laid down by nature and are the result of erosion and of natural water classification, the shape of the sand grains in themselves gives a clue to certain of their physical characteristics.

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Steel Division of A.F.A.

Sand Grain Shapes

The angular grains must have sharp cleavage planes and must be weak or they would not have broken into angular forms. They will probably be weak in handling, and will probably break up more or less readily when exposed to heat shock. Subangular grains are fractured grains which have been partly rounded, and round grains have withstood erosion or abrading movement without fracture. These characteristics have a direct bearing on the suitability of any sand reclamation system, as will be explained later.

The chemical composition of the sand grains may be of great importance. The grains suitable for foundry use must be substantially pure silica. A few other materials such as zirconium silicate offer some possibilities (in spite of their expense), but silica sand is and will probably remain the basis of foundry practice.

The sands themselves may be colored by impurities, and these impurities have a slight effect on the suitability of the sand for foundry use because they, in the main, lower the sintering point of the sand. Relatively large numbers of grains containing a considerable portion of iron oxide will not affect castings adversely unless they are subjected to intense heat for a long time, or when certain other impurities such as calcium carbonate are present.

Surface Condition

Another characteristic of sand which is important is the condition of the surface. If the sand grains are heavily pitted or very irregular in shape, they will absorb more oil or other bond to attain the required strength and other physical characteristics. (Examination of cuts will explain this.)

With the foregoing in mind, there are three general methods of producing good sand from waste sand: (1) The dry system, (2) the thermal or burning system, and (3) the wet system.

The dry system has been in use for many years and falls short in its end result. The lumps of sand are broken and the material moved with more or less agitation through a series of screens and through a column of moving air, the velocity of which is adjusted to throw off the dust.

The process serves admirably to open up tight sand, and it has permitted an overall saving of considerable importance. The resulting product is generally not usable where rebonding must be done with oil, and has not generally been successful as a substitute for new silica sand, either naturally bonded or washed.

One of the weaknesses of the dry system has been the amount of wasting. Currents of air cannot differentiate between clay and sand and, in order to remove a substantial proportion of the clay, relatively large percentages of silica fines are removed. In one case which came under observation, this percentage of removal into dust collectors amounted to about 30 per cent of the total weight processed, and relatively large additions of silica flour or float sand had to be made to prevent penetration.

Thermal Process

The thermal process relies for its effectiveness on volatilizing or burning the carbonaceous materials, that is, residual oil and carbon, including various washes which have coated the sand. This system was described by Hartley* in 1943. The sand is, in general, brought up to temperatures above 1000° F., the volatile matter burned off, and any clay particles or dust removed by air separation from the end product. The sand is then cooled and re-used.

The third method will be gone into in more detail. It is essentially a process of wetting down core and molding sand, breaking down the lumps in a wet crusher, scrubbing this sand by pumping or by additional means when necessary, classifying out the dirt and undesirable fine material to reproduce a sand of

*W. L. Hartley, "Thermal Process of Core Sand Reclamation," TRANSACTIONS, American Foundrymen's Association, vol. 51, pp. 207-209 (1943).

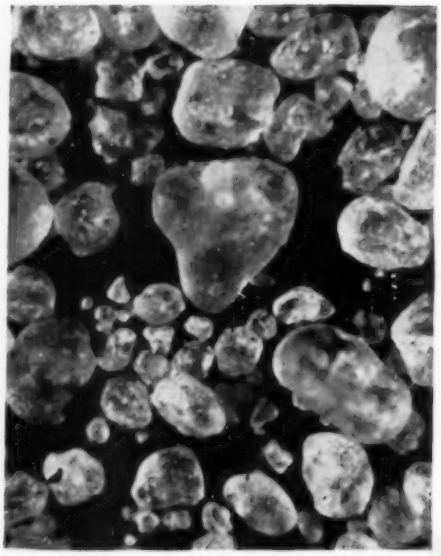


Fig. 2—New gray iron sand, 40x. Same sand as shown in color in Fig. 5. (Reduced one-third for reproduction.)

the grain size and distribution desired, dewatering and drying.

No particular details of the system itself are included in this paper, and the process is described only insofar as it will clarify thought on the end result. Work on this process was begun in an orderly manner before 1935, and encouraging results were obtained on certain sands in 1936.

It became apparent very early that, although many people have made attempts in this field, no standards had been set up. Short of putting in a full-production installation in a going foundry, there seemed to be no way of telling whether any given product was suitable for re-use.

Wet System Installation

A full-scale installation was eventually put in and operated successfully.* However, it told much less than was expected. It merely proved that, with that particular practice and with those particular castings, the sand was satisfactory. This first attempt was made in a steel foundry in which approximately 15 tons of sand an hour pumped against rather excessive heads producing a scrubbing action, and the sand then classified, dewatered and dried. Much credit must be given this foundry for its pioneering courage.

After a somewhat extended period of incredulity, another foundry making steel castings of much greater variety and with a somewhat different sand put in a system operating at 5 tons an hour. The yields of recovery in both cases were better than 85 per cent of the possible yield.

Both of these foundries used bentonite, and some of the sand treated had been bonded with oil, but the percentage of oil-bonded sand was relatively small and no conclusions could be based on those results for

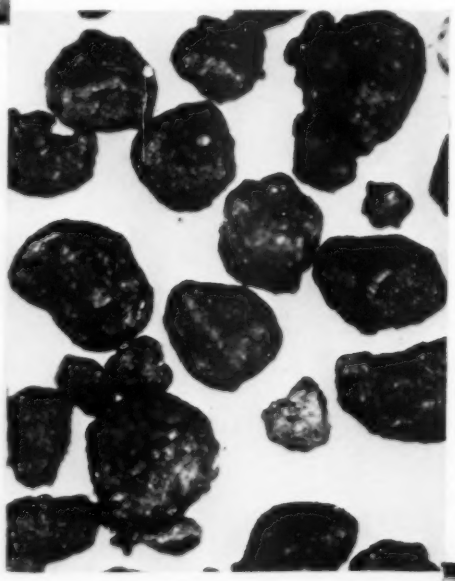


Fig. 3—Discard gray iron sand, 40x. Same sand as shown in color in Fig. 6. (Reduced one-third for reproduction.)

sands bonded essentially with oil, with pitch or with resins of various types. Sand from both of these foundries was suitable for making oil sand cores where they were needed, and there was no essential difficulty in providing sand suitable for making a small proportion of oil sand cores in these two installations.

It became apparent long before the second system was in operation that a great deal of work would have to be done on the determination of standards and means of measurement, particularly of cleanliness. How clean is clean for any given purpose?

At this moment a large company had under contemplation a new foundry in which it was proposed to include a sand recovery system of some sort. The development of the wet reclamation process had arrived at a point where the results could be of some assistance, and a long series of tests were carried out in the company's and author's laboratories, using the same oil, the same sands, the same methods of ramming and of baking.

A great variety of scrubbing means were explored in this connection, but for the purposes of measuring the cleanliness of foundry sands in steel and gray iron, a comparison of tensile strengths of new sand, of approximately the grain size and distribution, with the recovered sand proved to be a satisfactory index.

There are other important criteria. One of the possible significant measurements is permeability. The permeability of the treated sand is generally slightly higher than the permeability of new sand. This may result from the presence of a number of smaller particles in the new sand, chiefly organic matter or certain surface adhesions, usually iron oxide.

Any reclamation process tends to eliminate fine material, but there is no reason why these fines cannot be recovered also if it is worth while. Experiments now are being conducted with the recovery of silica flour and silica fines of below 140

Fig. 4—Reclaimed gray iron sand. 40x. Same sand as shown in color in Fig. 7. (Reduced one-third for reproduction.)

*Howard Mason, "Steel Sand Preparation by the Wet Method," TRANSACTIONS, American Foundrymen's Association, vol. 49, pp. 1115-1131 (1941).

mesh from the clay and bentonite sludge in a steel foundry.

A separate system sometimes is desirable because these fine materials are generally used in facing and should not be distributed throughout the sand. Some permeability aspects in connection with classification will be brought out in another paragraph.

Sand Flowability

Another characteristic of sand which might be examined is flowability. This subject has aroused so much discussion and contradiction that no special point is made of this measurement at this time. However, it might be said that reclaimed sands, with any core blower or when using a slinger or any of the various molding machines, have not yet shown any marked variation in behavior from that encountered when using new sand.

Of very much greater importance than permeability or flowability is loss on ignition and gas evolution. Gas evolution measures the quantity of gas evolved when the specimen is heated to a temperature of 1800° F. Loss on ignition is merely loss in weight upon ignition.

Gas evolution is primarily important in sands used for the light metals and other alloys. Certain additions to the sand for these metals tend to produce gases in rather large quantity, and sands should, therefore, be as free from gas as is practicable in order to minimize as far as possible the danger of blowbacks, etc.

Cleanliness of Sand

The final test of cleanliness is frequently overlooked. It is a study under a relatively low-powered microscope. The character of the surface, the percentage of each surface shown to be absolutely clean and the color of the residual material will, after a little experience, give important information.

The actual color of the pile of sand is of relatively little importance. With proper characteristics it could be yellow or green or blue, and no one would care so long as good castings could be made by using it.

A number of other indications will serve as indices to cleanliness. If the sand is readily dewatered the surface of the sand grains is free from absorbent material. The ease with which the sand will "wet out" in water is likewise quite significant.

In practical experience, it may be said that where reclaimed sand has been used successfully in making castings, this sand had a tensile strength, under conditions previously described, substantially equivalent to that of new sand of the same grain size and distribution, and that the gas evolution showed little if any increase. Until there is full evidence to the contrary, it will be assumed that the tensile strength is of prime importance only where certain types of bond are used. In the manufacture of light metal castings or in cases where the oil is not exposed to sufficient heat for a long enough time to burn itself out, tensile strength is a factor.

In the latter case a gummy residue, unless removed, may actually increase the tensile strength. In such cases, of course, the gas evolution would show a startling increase.

Cleaning Sand Grains

As to the method of cleaning the grains, several factors should be noted. Many types of sand, particularly those bonded primarily with clay or bentonite, are readily scrubbed and are usually sufficiently free from dead bond on the surface of the individual sand grains after controlled pumping and classifying. Within rather narrow limits, the efficiency of the abrasive pumps as scrubbers may be increased by artificially increasing the head and the speed of the rotor in the pump. If this is carried to a great extreme, the pump will wear out unduly.

It was found, for example, in an orderly determination that a difficult sand could be cleaned adequately by pumping 19 times against a head of 100 feet. This could be accomplished, of course, by pumping in a circuit and bleeding off a suitable proportion of the material as a finished product.

From an engineering standpoint, exaggerated treatment in a pump is unsatisfactory, and the pumps should be considered primarily as a convenient means of conveying and only incidentally as sand scrubbers. In the pumps, as in other forms of scrubbing devices, round grains are easier to clean than subangular sands, and subangular sands are easier to clean than angular sands.

In the process employed for these tests, scrubbing is accomplished by the action of one sand grain upon another. It is a kind of kneading action done with controlled moisture content to give a minimum of breakdown and maximum of rubbing. The sand grains thus freed of the bond material will fall through a rising column of water of suitable velocity and the fine material will be carried away. The subject of classification, in itself, offers material for almost unlimited discussion but only the following remarks will be made.

Classification Limits

Classification is a phenomenon dependent on surface tension of the medium and density of the solids. However, the density becomes less important as the materials become finer and their proportion of area to mass increases, as shown in Table 1.

It is fortunate that the practical limits of simple water classification lie rather closely within the limits of sands generally used in foundries. It is fairly easy, for example, to produce a sand free from material below 140 mesh or below 120 mesh

Table 1

RELATION OF SURFACE AREA TO SCREEN SIZE

(Area of Sphere = πD^2)

Screen No.	*Opening, in.*	*Area per Grain, sq. in.*	*Grains per Cu. In.*	*Area per Cu. In., sq. in.*
6	.131			
12	.065	.05388	443	23.6
20	.0328	.01326	3,630	48.2
30	.0232	.00336	28,400	95.4
40	.0164	.00169	79,000	133.5
50	.0116	.00084	226,000	188.0
70	.0082	.00042	620,000	260.5
100	.0058	.00021	1,810,000	380.0
140	.0041	.00010	5,100,000	510.0
200	.0029	.00005	14,500,000	725.0
270	.0021	.00003	41,000,000	1,230.0
Pan		.00001	108,000,000	1,490.0

Table 2

COMPARISON OF NEW AND RECLAIMED CORE SANDS

Screen No.	Steel Sand: Discard, per cent Retained	Steel Sand: New, per cent Retained	Steel Sand: Reclaimed, per cent Retained	Gray Iron Sand: Discard, per cent Retained	Gray Iron Sand: New, per cent Retained	Gray Iron Sand: Reclaimed, per cent Retained	Non-Ferrous Sand: Discard, per cent Retained	Non-Ferrous Sand: New, per cent Retained	Non-Ferrous Sand: Reclaimed, per cent Retained
6	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
12	0.04	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00
20	0.08	0.04	0.04	6.70	0.10	0.00	0.04	0.00	0.12
30	2.90	2.36	2.70	5.44	0.66	0.74	0.20	0.02	0.16
40	32.96	25.80	37.80	12.82	9.20	7.02	4.16	1.46	3.76
50	32.80	35.24	41.40	41.26	49.80	43.00	44.56	43.44	49.26
70	11.10	17.22	13.64	20.26	22.24	29.58	36.00	44.20	36.80
100	5.10	10.46	3.70	5.66	6.34	9.54	11.02	10.26	8.78
140	2.60	4.36		4.02	6.78	6.64	2.00		1.00
200	1.34	1.50	0.30	1.74	4.18	2.86	0.40	0.46	0.10
270	1.50	0.34		0.22	0.42	0.40	0.10		0.02
Pan		0.46		0.24	0.02	0.20	0.02		
Clay	9.56	1.60	0.20	0.36	0.18	0.00	1.50	0.16	0.00
Total	99.98	99.88	99.78	99.98	99.92	99.98	100.00	100.00	100.00
Physical Tests†									
Green Permeability	75	128	287	88	119	119	110	128	134
Dry Permeability	115	178	358	104	138	140	125	143	149
Flowability	76	90	91	85	88	89	92	92	92
Avge. Tensile Strength, psi.	26.5	158.0	171.0	5.0	225.5	236.0	136.0	169.5	177.5
Loss on Ignition, per cent	2.05	0.38	0.25	3.1	0.98	0.90	0.58	0.10	0.18
Gas Evolution @ 1850° F., cc per gram	8.8	1.6	0.0	10.5	1.4	2.0	15.0	0.0	2.0

†Oil to Sand Ratio: 90 to 1 (by weight). All tests made in accordance with A.F.A. Standards.
*Indicate total grains remaining on sieve nos. within the brackets.

or below 100 and 70 mesh, whereas it is quite difficult to make a separation between 400 and 500 mesh material. The problem then becomes an engineering problem of classifying and dewatering and finally drying the sand grains.

Table 1 is wholly theoretical and is based on spheres all of one size, but it serves to show some facts about classification as well as some facts about rebonding core sands.

The same characteristics that modify and limit wet classification are true in a somewhat different range with air separation. It is the surface tension of the air which makes fine particles float, the primary difference being that air is compressible and it changes its density rather rapidly with temperature changes, whereas water is relatively incompressible and the changes in viscosity up to the boiling point are not great enough to affect classification for our purposes to any practical degree.

Comparisons of Sands

Attention is called to Table 2 showing comparisons of the screen analysis of new and reclaimed sands together with the other records considered essential for comparison. One of these is from a steel foundry, one from a gray iron foundry making large miscellaneous castings, one from a gray iron production foundry using oil-bonded cores which burn out, and one from a magnesium foundry.

Photographs in color of a few of these characteristic sands, processed chiefly by the wet method, are shown. One or two photographs show, in a rather exaggerated way, some of the characteristics which limit the burning process (Figs. 5 through 14, pp. 52-53).

Steel Foundry Sand

Data are available in some detail on a number of commercial operations in steel foundries. One foundry produced slightly over 52,000 tons of castings and used the equivalent of 2½ tons of new sand per ton of castings produced, or approximately 125,000 tons of sand in somewhat less than a year. Another instance shows the washing and use of approximately 100,000 tons of washed sand during 3½ years. Another foundry has used this sand satisfactorily at the rate of 35 tons per day for 3 years, making a total of 27,300 tons.

From five other plants, complete data are not yet available, although we understand that there is a paper in preparation which analyses the economies made by the use of sand at $12 a ton with a reclamation system as contrasted with sand at $2 a ton without reclamation.

A summary of what might be reasonably expected of a wet sand recovery system may be of interest.

1. The color will not usually match that of new sand. It may be gray. This grayness is the result of small amounts of black carbonaceous material lying in the cavities on the surface of the sand grain and which cannot be readily and economically removed by the process of wet scrubbing the sand grains.

2. Grain size and distribution of the sand may be controlled within limits. These limits are determined by the grain size and distribution of the sand put into the system. Larger sand grains may be screened off at the beginning of the process and classifiers may be adjusted to remove fine material.

Water Separation

In some instances it is practicable to make a water separation of two or more classes of sand which will lie on coarser or finer screens. Such a division of sand is difficult, chiefly as an engineering problem, because it may involve duplication of dewatering and drying equipment or the successive treatment in the same equipment, first of one class of sand and then the other.

3. Cleanliness of sand, apart from color, can be determined by physical characteristics, as previously described.

4. Tensile strength should be sub-

A sand reclamation unit installed in one of the country's largest war plants.

stantially equal to that of the equivalent new sand.

5. Sintering point will not be reduced.

6. Moisture content will be controlled to a close degree.

7. The temperature of the dried sand will be constant at a useful temperature.

8. The sand will be usable in molding machines, core blowers and slingers.

9. The baking time of cores will probably be different from that of new sand, but should be within a practicable range.

10. Sand when tempered should not dry out too readily. In this connection, the scrubbed sand will often tend to dry out more readily than new sand because it contains less organic material. This can be remedied by the addition of minute amounts of clay.

11. The hardness of the cores made from sand reclaimed mechanically should be sufficient.

12. The sand will require no more bond, particularly bond of the gas producing varieties, than was required for new sand and should, of course, not require any more from the point of view of economy. It may also be expected that a wet sand reclamation system will continuously remove and discard the weak and cracked grains.

This paper has not made any point of the effect of a wet sand reclamation system on dust control. It certainly offers advantages in this direction. The dust producing grains are largely taken off in the waste from the classifiers as slimes, the action paralleling to some degree that of wet dust collecting systems which may and, in fact, frequently do use common disposal tanks and other apparatus.

Acknowledgments

Thanks are extended to Eastman Kodak Co. for the painstaking work on the reproduction of color slides; to the Cincinnati Milling Machine Co.; and particularly to H. M. Rishel and C. H. Walcher of American Steel Foundries, as well as to the 100 or more progressive foundry superintendents who have shipped us their sands for study, in many cases making castings with the resulting material. Reference also is made to J. G. Pearce, of the British Cast Iron Research Association, to Mr. Buchanan, of Glasgow, to Charles Shaffer, and particularly to the stimulating incredulity of some other foundrymen whose attitude urged us to greater efforts.

Management, Are You Accepting Your Responsibility?

By M. D. Johnson,*
Factory Works Manager,
Purolator Products, Inc.
Newark, N. J.

Dimension checking and visual inspection of a steel casting.

IN the writer's opinion, one of the most important contributions the American Foundrymen's Association has made to the foundry industry has been the work done in calling to the attention of the various foundries the need for satisfactory inspection of castings. This phase of the American Foundrymen's Association program has been materially increased in the past year and a half with the appointment of a national casting inspection committee.

Local Committees Urged

It is hoped that as a result of this committee's work, the individual chapters of the American Foundrymen's Association will appoint local casting inspection committees to further investigate the importance of this program. Even though the value of inspection of castings has been raised and brought to the attention of those involved as much as it has, it is surprising to see the great number of foundries that do not have any recognized inspection organization whatsoever. Invariably, the foundries without inspection organizations are those from which are received castings far below what should be considered normal commercial quality.

In the work of the Inspection of Castings Committee attention is often called to the value of such inspection processes as x-ray, gamma ray, and magnetic particle inspection, but the factor that should concern most foundries is the value of just straight visual inspection.

It is not the intent to imply that these more critical types of inspection are not necessary. However, there is no need of worrying about such types of inspection as long as castings are shipped from foundries to ultimate users with cracks and blow holes so large that they not only can be seen plainly with the naked eye but many times are of such size that one can insert a fingernail or whole finger in the obvious defect. For some reason or other it has been difficult to bring this serious condition to the attention of the greater part of foundry managements.

Two Factors

We cannot help but feel that the shipping of such obviously defective castings is caused by two factors. First, in the foundry that does not have an inspection organization, invariably that foundry management depends on normal segregation of defective castings by both the cleaning room and the shipping room supervision and workman. It is natural that in these trying times ultimate users emphasize the need of a certain quantity of castings. It is just as natural that the cleaning room and shipping supervision will have as their main objective the shipment of the quantity of castings rather than to ship lesser quantities with the defective castings thrown out. Second, too often foundries talk in terms of the percentage of yield, but they look on this yield as the tonnage actually shipped from the foundry rather than the ultimate yield which would take from this the tonnage of castings rejected by the final users.

Many Users Served

There is no question but that all foundries serve many users, and these users of the castings have different standards of quality. However, if every foundry would institute an inspection program and discard the obviously defective castings which are of absolutely no value in any commodity, and then develop a more rigid method of inspection for the more critical users, then foundries, in general, would materially improve their standing in the industry.

We can think of no better way of concluding this article than asking you of Foundry Management if you are one who is willing to allow obviously defective castings to be shipped from your plant.

*Formerly Chief Inspector, Caterpillar Tractor Co., Peoria, Ill. Member and former Chairman, Inspection of Castings Committee, A.F.A.

Steel Castings RADIOGRAPHY

By E. L. LaGrelius, East Chicago, Ind., and C. W. Stephens, Granite City, Ill., Supv. Met., Research Lab., and X-Ray Dept. Foreman, Respectively, American Steel Foundries.

• ***Part I of this paper reviews briefly the underlying principles necessary for the production of good radiographs, proposes a concise radiographic terminology and lists the probable causes for casting defects revealed by radiography.***

A DISCUSSION of the advantages and limitations of radiography to the steel casting industry should be prefaced by a consideration of the underlying principles upon which the process is based.

The primary purpose of radiography is to disclose the presence of defects or discontinuities in the interior of a casting. This is accomplished by exposing a casting to a beam of X-rays which have the ability of penetrating through the casting without being completely absorbed. The absorption of an X-ray beam is dependent upon the amount of material it must penetrate — the greater the thickness, the greater the absorption.

Therefore, when X-rays pass through a casting containing a defect or discontinuity there will be a variation in the amount of X-rays absorbed. Photographic film is generally used to register this variation in absorption of the X-rays. The prerequisites for a good film are, therefore, that it will register accurately any variation in intensity of the X-rays passing through a casting, and that the absence or presence of a defect be clearly defined as to size and shape.

Fig. 6—Radiograph showing gas holes in casting as a result of imperfectly deoxidized metal.

PART I

The important purpose of this part of the discussion is to try to point out which factors an operator can control in producing a satisfactory radiograph.

Equipment

The first of these factors is the selection of equipment to produce the necessary X-rays. This is dependent upon the size, shape and section thickness of the casting which the operator is required to radiograph. The time which can be allotted to securing radiographs and the number of castings are important factors.

Source of X-Rays, kilovolt	*Maximum Section Thickness, in.*
220 to 250	2
400	3
1,000	5
Radium	—

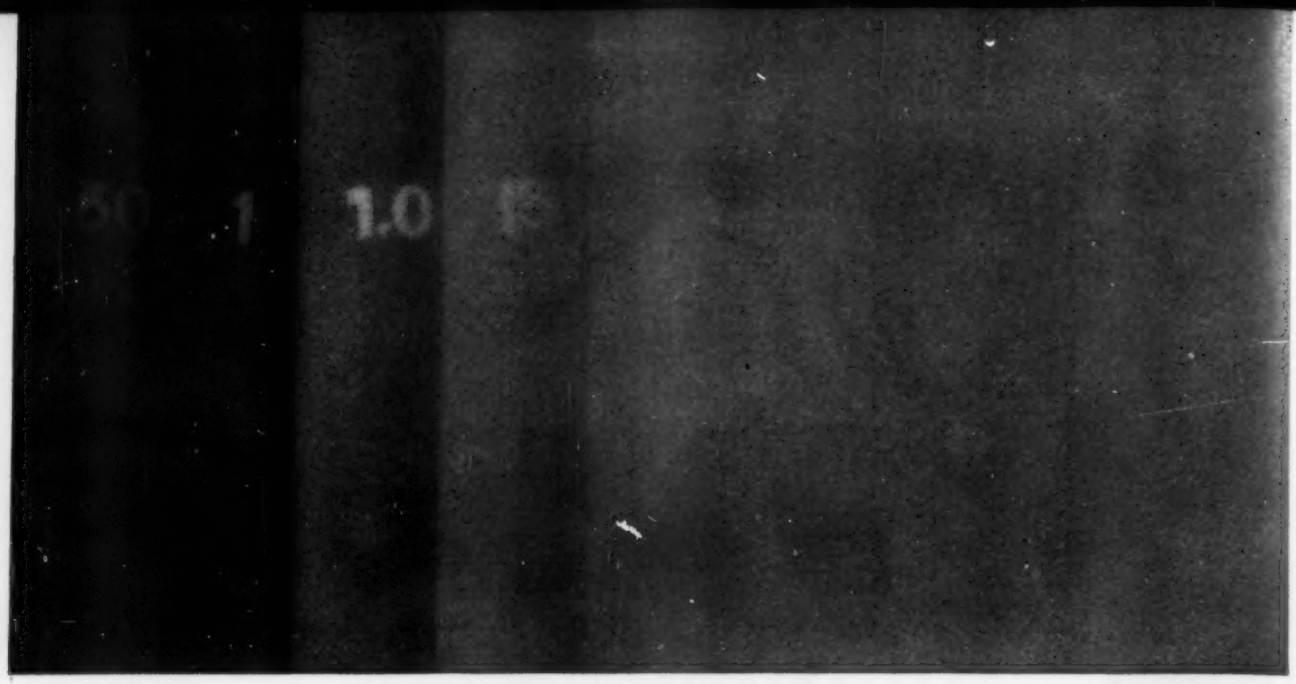


Fig. 2—High contrast film. Step block of 0.5 in., 1 in., 1½ in. and 2 in.

The selection of the unit which will be required also entails the construction of adequate building space, crane service and developing and drying equipment.

In selecting a unit the operator also exercises some control over the contrast of a radiograph. Contrast depends primarily upon the absorption coefficient of the metal, and the absorption coefficient is a function of the X-ray tube voltage. High voltages produce radiographs of low contrast, while low voltages produce radiographs of high contrast. Therefore, using the lowest voltage that will give a readable film in a reasonable length of exposure time is the general rule.

From the foregoing discussion, it would seem that contrast obtainable at a particular voltage should be independent of the thickness of a material, but this is not the rule because of the scattering of X-rays within the material itself. To date, the only practical device to reduce this scattered radiation is the use of 0.010 lead screen on both sides of the film within the cassette. The front screen acts as a filter for the scattered beam and the back screen acts as an intensifying screen.

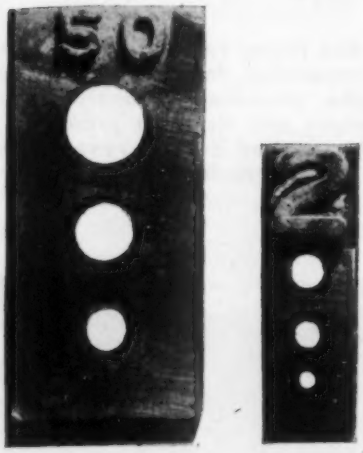
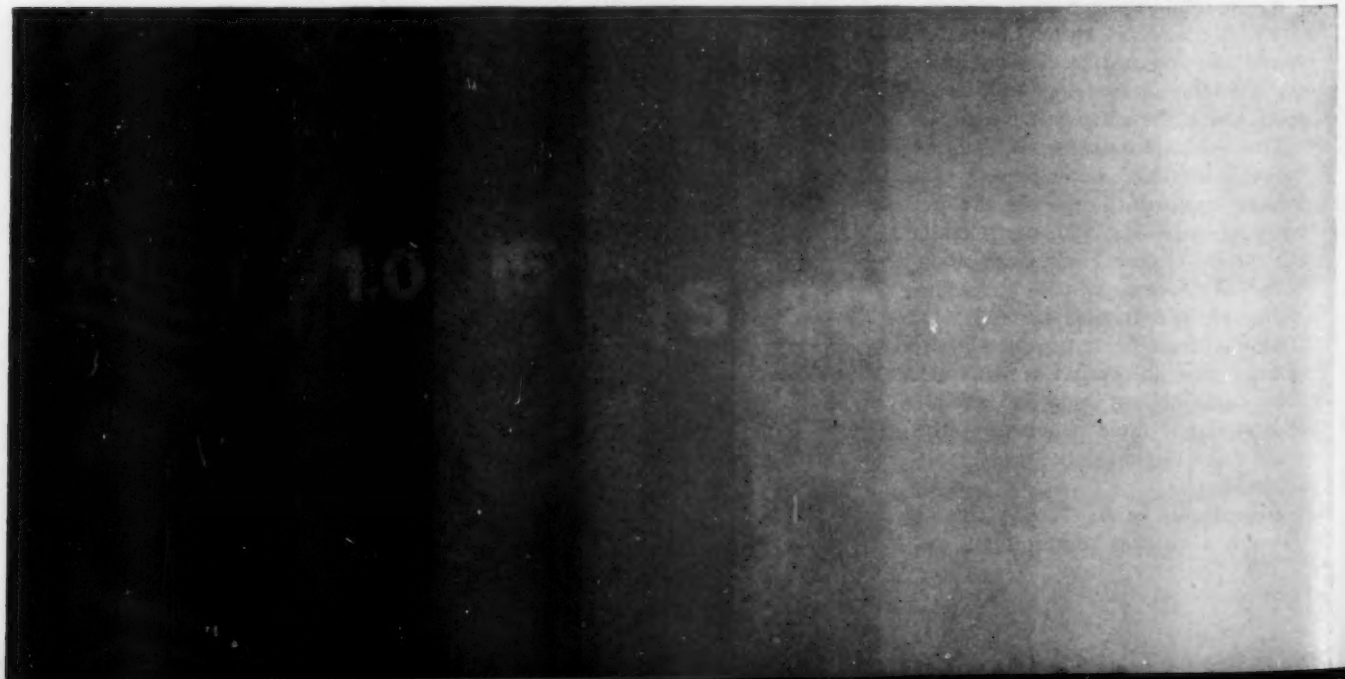


Fig. 1—(Above) Penetrameters used.

Fig. 3—High latitude film. Step block and procedure same as in Fig. 2.

Film

The second factor over which an operator has some control is the recording device; that is, the proper selection of film. Radiographers are always endeavoring to increase sensitivity. Sensitivity is defined as the



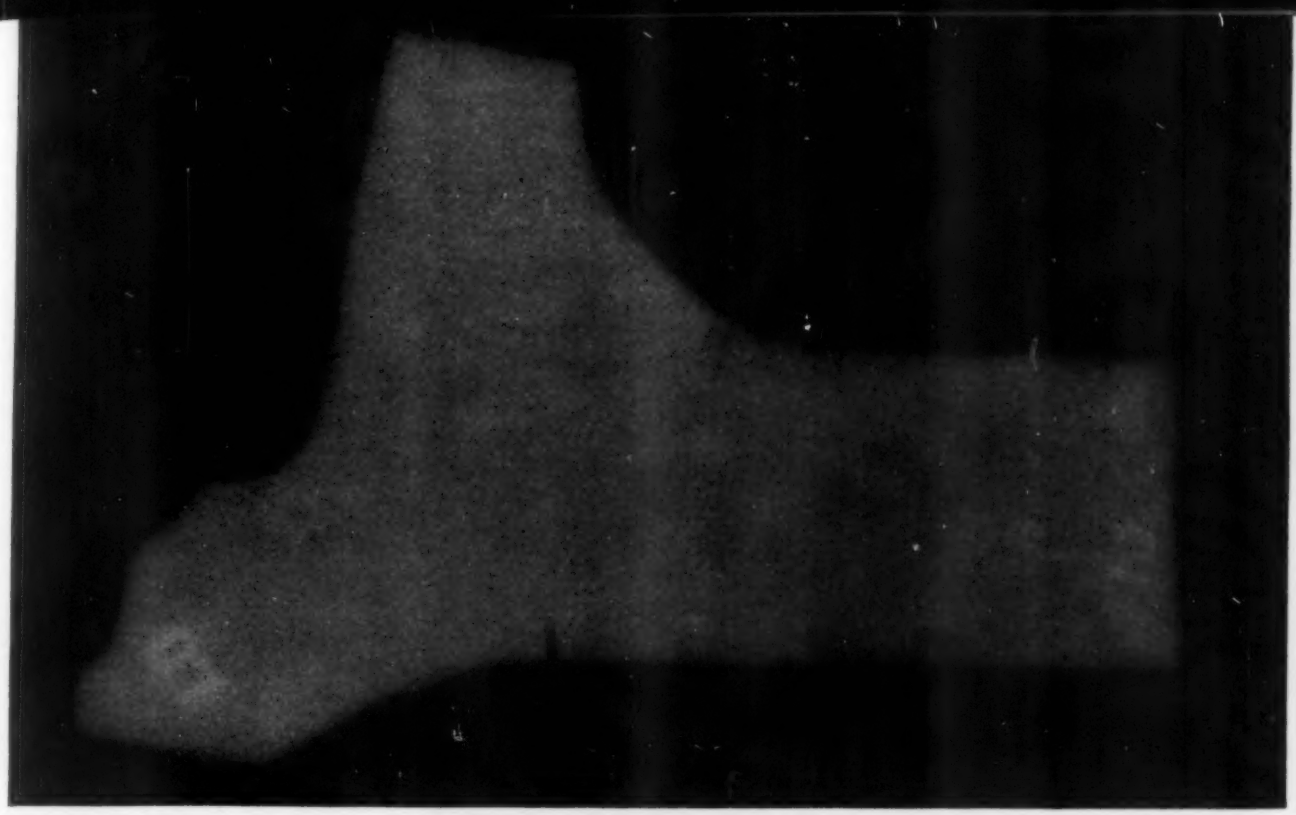


Fig. 4—Radiograph of casting using low density film.

smallest detectable defects in percentage, the size of defect to section thickness. Generally, a sensitivity of 2 per cent can be obtained. A defect of 0.02 in. would be located on a radiograph made of a one-in. section.

In order to determine whether or not a radiograph has the proper radiographic quality, in that all detail structures are visible indicating proper exposure technique, a penetrameter is used.

The penetrameter generally used consists of a thin sheet of the same base metal having the same density as that of the metal to be radiographed. Each penetrameter has an area of ½ by 1½ in. of a thickness equal to 2 per cent of the thickness to be radiographed. In each penetrameter there are three holes having diameters of 2, 3 and 4 times the thickness of the penetrameters, as shown in Fig. 1. A lead numeral indicating section thickness is attached to one side of the penetrameter.

The latitude characteristics of a radiographic film is the exposure range over which various defects are satisfactorily revealed when radiographs are made of castings having widely different thicknesses, as shown in Figs. 2 and 3.

The sharpness or detail of a radio-

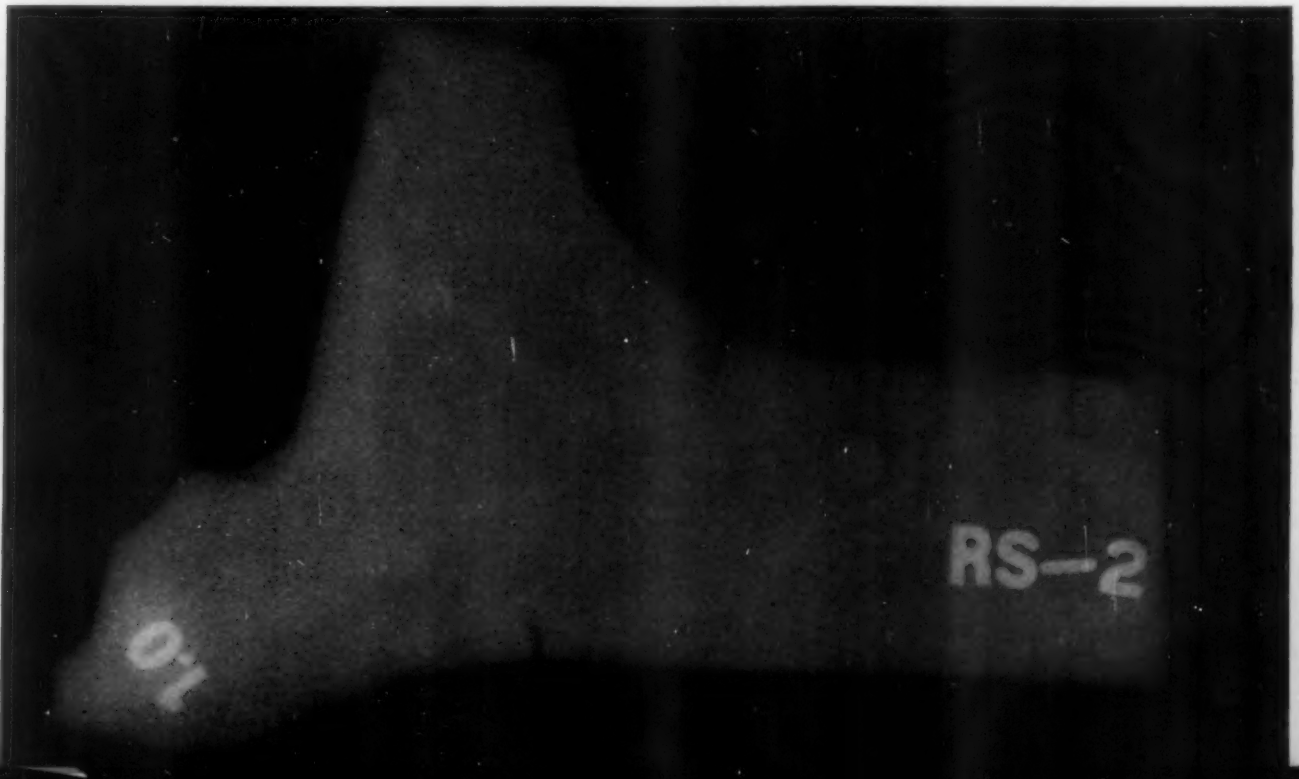


Fig. 5—Same as Fig. 4 except higher density film used.

Fig. 7—Radiograph showing gas holes in casting as a result of mold surface moisture.

graph is also dependent upon several factors. The eye detects images of low contrast if the outline is sharply defined. The sharpness of an image may be improved by changing to a smaller focal spot or by increasing tube to film source distance.

Manufacturers today produce three distinctive types of industrial X-ray film:

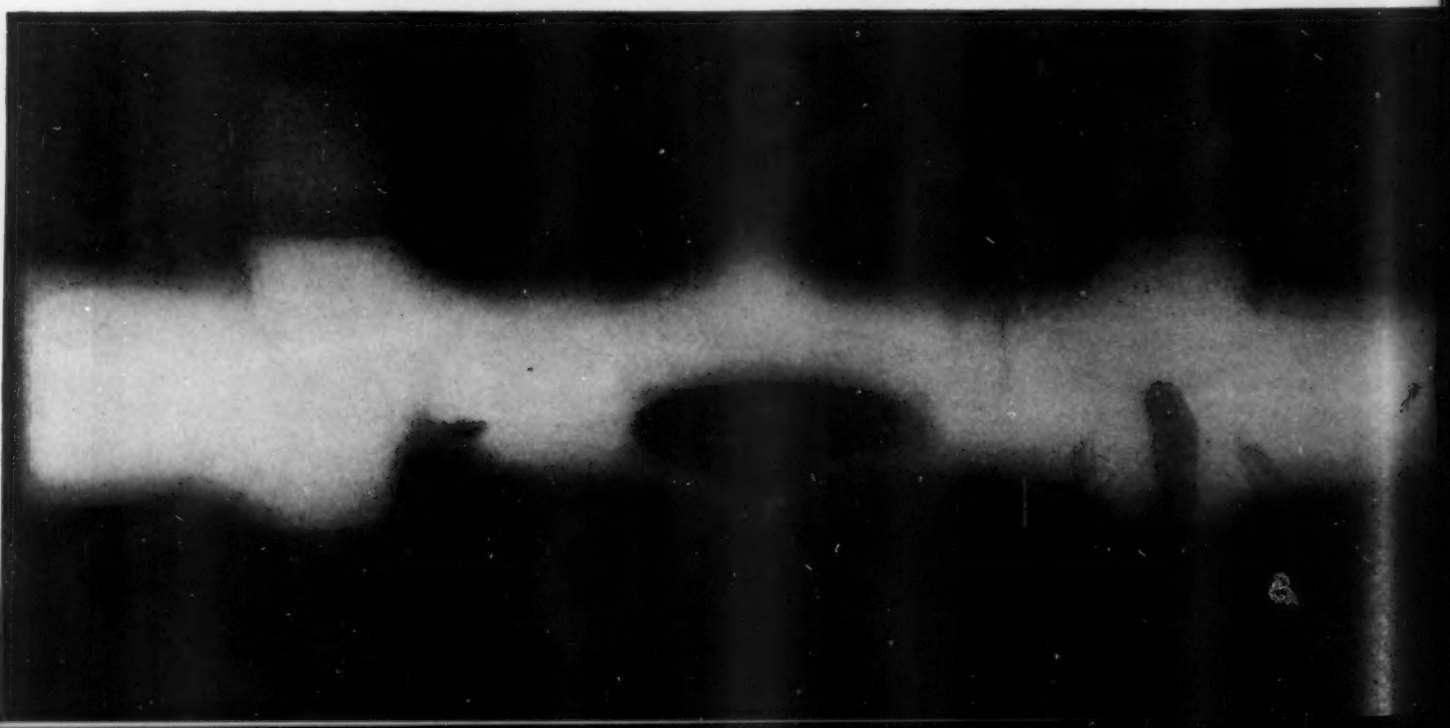
1. Slow — Fine grain (optimum definition), high contrast (optimum visibility and of low speed).
2. Medium — Large grain, medium contrast, 2½ times speed of slow film.
3. Fast — Large grain, medium contrast, 2 times speed of medium film.

An operator also must decide whether he wishes to use a film of high contrast or high latitude. A film of high contrast possesses a low degree of latitude, and a film having low contrast will possess a wide latitude. It is sometimes necessary when radiographing castings of varying section thicknesses to use a film having a wide latitude, because if a high contrast film were used the thinner sections would appear extremely black and the thicker sections so light that small density changes due to a small defect would be lost in the radiograph.

Fig. 8—Radiograph showing gas holes (due to entrapped air) and shrinkage cavities.

Radiographic Density

Radiographic density is defined as the degree of blackening of a film, and increases with increasing X-ray intensities. Density also may be defined mathematically as the log-



arithm of the reciprocal of the transparency of a film ($D = \log \frac{1}{T}$). Thus, a film density of 1.0 means that the blackening is such that only one-tenth of the incident light passes through. For a value of 2.0 only one-hundredth of the incident light passes through. Film densities have become greater, and better viewing equipment has been manufactured. We have experienced many times that harmful defects were not located on radiographs of low densities. Films having densities below 1.5 are unsatisfactory, and densities of 2.0 or over are better. By increasing the density, sensitivity also is increased, as shown in Figs. 4 and 5.

Secondary Radiation

Another influencing factor on the production of good radiographs is proper shielding of film from stray or secondary radiation, created by various objects surrounding film, walls, etc. Secondary or stray radiation does not form any part of the X-ray image and only creates fogging. The influence of these rays may be curtailed by shielding the cassette with sheets of lead on the back and sides.

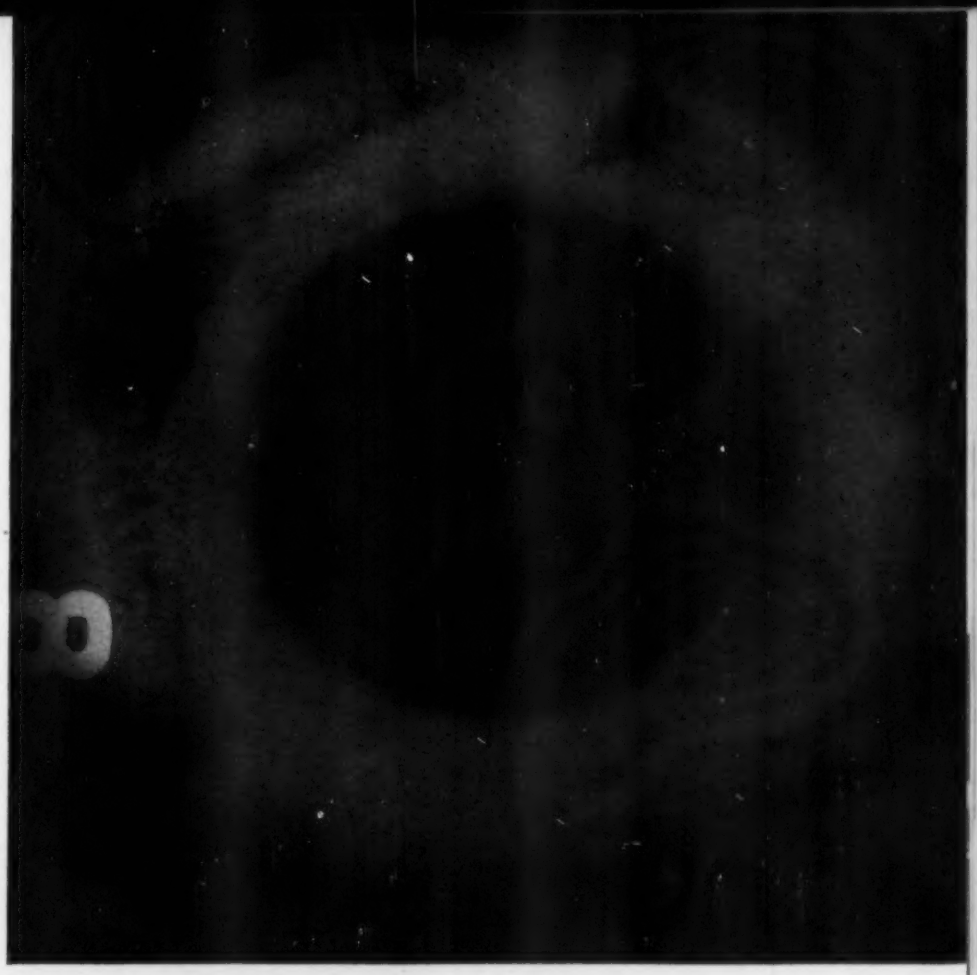


Fig. 9—Above—Radiograph of casting showing shrinkage cavity resembling gas hole.
Fig. 10—Below—Radiograph showing another type of shrinkage.

Now that we have sketched briefly the underlying principles of radiography, let us put these principles to use. The method of diagnosis, as applied to determining the type, size and shape of an image outlined by the variance of film blackening, is the same as the medical profession used in setting up its principles of film interpretation, dissection or sectioning. Once we have compared the image on a radiographic film with a visual inspection of the defect, we are able to state the type of defect in subsequent radiographs having the same image.

Application of Principles

It is well to remember a few vital facts when viewing radiographs: (1) Voids, cavities or other discontinuties in metal of uniform density will appear as dark areas on a film, whereas materials of higher density than the metal will appear lighter on the film. (2) Materials such as sand, ladle lining, etc., will appear as dark areas on the film. (3) Ex-

Figs. 11 and 12 (Above)—Radiographs showing shrinkage in castings.

Fig. 13—Radiograph showing sand trapped in metal during pouring operations.

cess metal on the surface (scabs, fins, etc.) will appear as light areas, whereas surface defects, scratches or depressions will appear dark.

Radiographic Terminology

It is important that a standard terminology be used in interpreting defects on radiographic film. Such a proposed terminology and the probable causes of these defects are given in the following paragraphs.

1. Gas Holes

Gas holes appear as round or elongated, smooth dark spots occurring individually, in clusters or distributed throughout the casting.

This condition is the result of imperfectly deoxidized metal; gas forming during solidification by the evaporation of moisture or volatile material from the mold surface; excessive evolution from a core on account of insufficient baking or venting; or the entrapment of air in the cope surface of a casting due to the inability of the gas or air to escape from the mold cavity before the complete solidification of the molten metal. Radiographs depicting various types of gas holes are shown in Figs. 6, 7 and 8.

2. Shrinkage

Shrinkage appears as a dendritic, filamentary or jagged darkened area.

This condition indicates insufficient feeding of a casting. This defect generally is found in the center wall section or under risers, thick-to-thin sections or improperly fed sections. Radiographs depicting various types of shrinkages are shown in Figs. 9, 10, 11 and 12.

3. Heterogeneities

3.1 Foreign material appears as isolated, irregular, or elongated variations of film blackening, not corresponding to variations in thickness of material nor to cavities. They may be due to the presence of sand, slag or oxides.

This condition is caused by particles of sand from molds or cores, trapped slag or other refractory materials trapped in the metal during the pouring operations. Radiographs of foreign materials are shown in Figs. 13 and 14.

4. Sharp Discontinuities

4.1 Hot cracks appear as ragged dark lines of variable width and numerous branches. They have no definite line of continuity and may exist in groups. They may start at the surface or be internal.

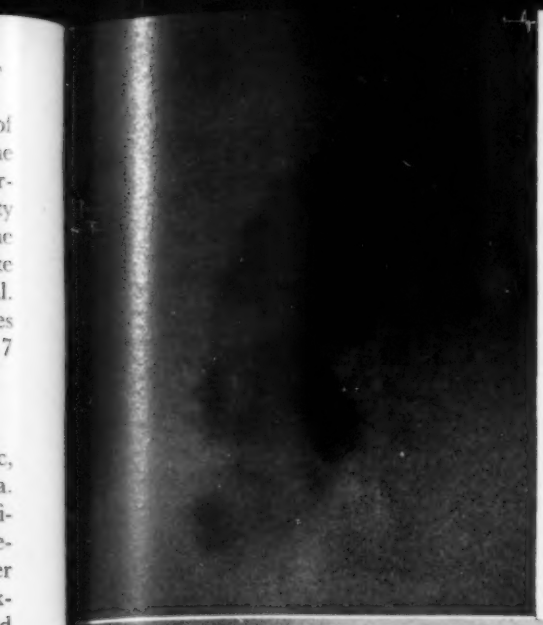


Fig. 14 (Left)—Radiograph showing slag in casting.

Fig. 15 (Below)—Radiograph showing hot cracks in casting.

This condition is the result of the normal contraction of the casting which was restricted by the mold and/or core during or immediately after solidification, the magnitude of the restricting forces being greater than the strength of the metal in the casting at that time. A radiograph of a hot crack is shown in Fig. 15.

4.2 Cold cracks appear as a straight dark line, usually continuous throughout its length, and generally exist singly. These cracks usually start at the surface.

Cracks of this nature may be produced in castings being cooled from an elevated temperature during flame burning, grinding or quenching operations. Any of these operations may produce stresses that exceed the strength of the metal in the casting at some time during or after the operation. Examples of cold cracks in castings are shown by radiographs, Figs. 16 and 17.

4.3 Cold shut appears as a distinct darkened line in bands of variable length and definite smooth outline.

Cold shuts are produced when two or more streams of molten metal flowing from different or similar directions fail to unite and form homogeneous metal. The basic cause for the occurrence of a cold shut is that the two bodies of molten metal which meet are at too low a temperature to join together. The surfaces of the cold shut may or may not be oxidized, depending on the magnitude of the defect. Cold shuts may be produced by interrupted pouring, slow pouring or the use of molten metal too low in temperature for the casting in question.

5. Miscellaneous

5.1 Surface irregularities are any image corresponding to an irregularity visible on the surface.

5.2 Misruns appear as prominent darkened areas of variable dimensions with a definite smooth outline.

Misruns are produced by the failure of molten metal to fill the section of a casting, leaving the region void, generally on account of pouring too cold metal.

The general principles and the diagnosis of various defects that may be found in steel castings by the use of the X-ray, having been discussed briefly, their application to a par-

Fig. 16 (Below)—Radiograph showing cold crack in casting.

This paper, dealing with the underlying principles of the radiographic process, was secured as part of the 1945 "Year-Round Foundry Congress" and is sponsored by the Steel Division of A.F.A. Part II of the paper discusses the application of the general principles of radiography to a production foundry.

Fig. 17—Radiograph showing cold crack (light section) in casting.

ticular foundry will be discussed in Part II of the paper.

Acknowledgment

Acknowledgment is made to the personnel of the radiographic laboratories of the Granite City Plant, Indiana Harbor Plant and Cast Armor Plant of the American Steel Foundries for their assistance in preparing and selecting radiographs, to C. H. Walcher, Works Manager of the Granite City Plant, and to G. A. Lillieqvist, Research Director, for their assistance in preparing the manuscript.

PART II

THE company with which the authors are associated has two one-million volt X-ray machines in its Granite City plant.

An exterior view of the X-ray building of this plant is shown in Fig. 1. It consists of a loading room, two separate X-ray set-up rooms, two control rooms, one dark room, and an office.

The loading room (Fig. 2), which is 31 x 20 ft., has a 3-ton overhead crane and leads into both set-up rooms. In this room castings are transferred to trailers and moved into the set-up rooms.

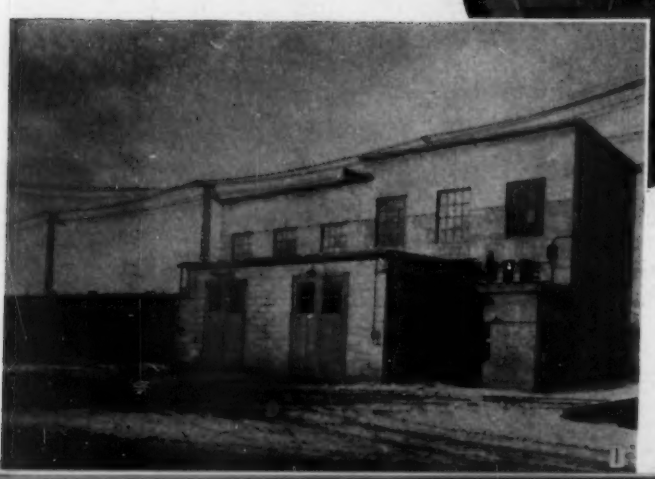
Figure 3 shows one of the set-up rooms, displaying the X-ray head. This room is 25 ft. square and 32 ft. high. The walls are of concrete, the lower 16 ft. are 18 in. thick, and the upper 16 ft. are 12 in. thick. This provides adequate protection from the X-rays. The other set-up room is identical in size.

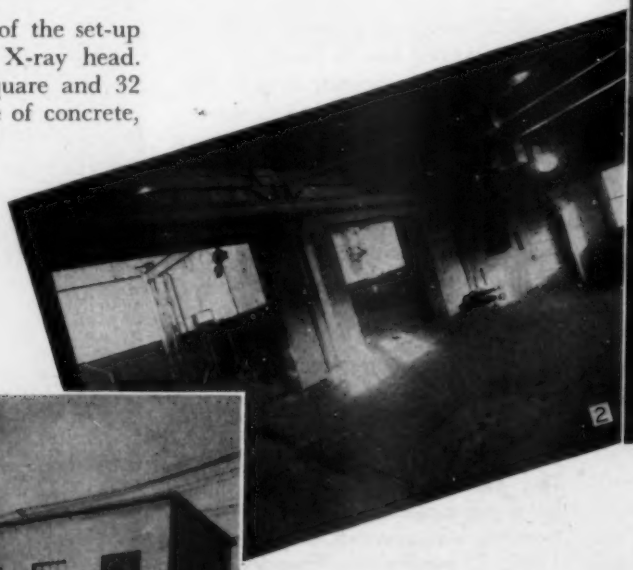
Figure 4 illustrates the control panel of a million volt X-ray machine. The operators are protected by a 36 in. concrete wall while operating this panel.

The dark room, shown in Fig. 5, is 21 x 24 ft. and L-shaped. There are two separate developing units, one horizontal dryer and three vertical dryers, which provide ample developing and drying space for efficient departmental operations.

The office part of the building is 25 x 38 ft. and L-shaped. Note in Fig. 6 how convenient the dryers are to the table where the film is assembled.

The other part of the office is used for studying film (Fig. 7). Note the four-panel illuminator used for viewing several films at once. This arrangement is convenient for





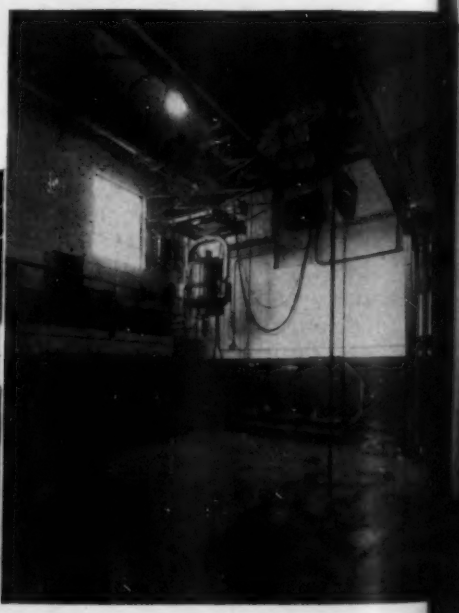


Fig. 1—Exterior view of X-ray building. Fig. 2—Loading room where castings are placed on trailers for transport into set-up rooms. Fig. 3—An X-ray set-up room equipped with a one-million volt X-ray machine.

comparing like positions on different castings.

At this plant the two one-million volt X-ray machines are used exclusively in two important fields: (1) In the developing of foundry technique in the production of steel castings, and (2) in the non-destructive inspection of steel castings.

In developing foundry technique, sample castings are poured and X-rayed in their entirety. The films are inspected by the X-ray department and possible comparisons are made. These, along with the readings and findings, are reported to the Management and Planning Committee. (The Management and Planning Committee consists of the Superintendents of the Foundry, Inspection, Core Room, Pattern Shop and X-ray departments.)

The films showing defects, or unsatisfactory areas, are reviewed and discussed. The best results have been obtained by placing the picture (the film) of the unsatisfactory areas on the casting as it was originally X-rayed. This leaves no room for doubt or misunderstandings. Plans to eliminate undesirable conditions are agreed upon. Thus, in a short time, the casting has been inspected, and changes in technique or design to eliminate defects in unsatisfactory areas may be made.

A splendid example of this X-ray procedure may be illustrated in the development of one casting. The specification on this casting called for radiography. One casting was poured for a sample and X-ray proved the casting to be unsatisfactory and that a number of changes would be necessary. Then changes were made by members of the Management and Planning Committee.

In re-sampling the pattern, four castings were poured, each having a different gate and riser. Each casting was completely X-rayed. The films were compared, area for area, to determine the best method. After selecting what was thought to be the best combination of practices or techniques, two more castings were poured. These two castings were found to be greatly improved. Production was started and the first casting was X-rayed and found to be satisfactory.

Beginning with Fig. 8, some sample castings are shown which have been improved due to the X-ray studies made.

Figure 8 shows an area of a sample casting with clear indications of a dirt and gas condition which had to be corrected.

Through the efforts of the committee a suggestion was made to move the riser to a new position, and as a result a sound casting was produced (Fig. 9).

An example of serious shrinkage and dirt present in a machined area is shown in Fig. 10.

Figure 11 shows the same machined area in a later casting after a riser had been added. This casting was X-rayed after a riser had been burned off, and the majority of defects present are on the surface.

Considerable shrinkage can be seen in the 2 in. X-rayed section shown in Fig. 12.

The same area in Fig. 13 reveals no shrinkage due to the following changes: At both ends, where the serious shrinkage had been present, the metal was reduced to 1½ in. due to a drawing revision. Then by adding a riser in the center of the two shrink voids it was possible to eliminate the shrinkage.

A severe shrinkage condition can be seen in Fig. 14. This defect was found in a 3-in. section around a lifting lug.

After a feeder, running from the riser, had been added, a sound casting was produced (Fig. 15). The

Fig. 4—Control panel of million-volt X-ray machine. Fig. 5—View of dark room showing developing units and dryers. Fig. 6—Assembling the X-ray film. Fig. 7—Four-panel illuminator for simultaneous viewing.

marred sections are surface burns showing where the feeder was burned off.

In all of the above cases the committee played a prominent part in remedying the defects found in the sample castings. Cooperation between all members means much in the saving of time, labor and money.

After the practice was developed, a spot check was made on every 25 castings. In this spot check, two areas were found to have developed serious trouble. Therefore, some minor changes were made and the castings checked by X-ray to determine if satisfactory. Since that time approximately every 25th casting has been checked and only a few minor changes have been necessary.

In the development procedure just described, castings are sometimes sectioned as a supplement to X-ray. In normal X-ray technique only two dimensions are shown. Sectioning will give the third dimension and the average foundryman will obtain a clearer conception of the defect.

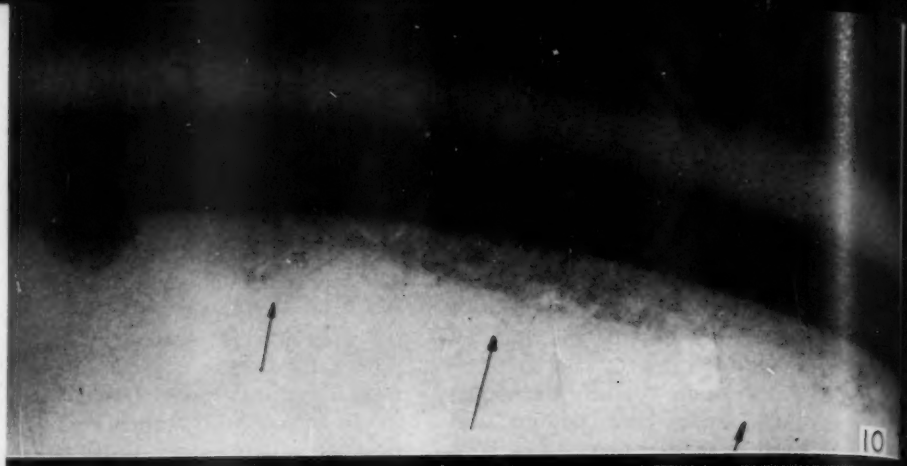


Fig. 8—Defects seen in a casting through the use of X-ray. Fig. 9—Improved area following repositioning of riser. Fig. 10—Serious shrinkage and dirt in a machined area. Fig. 11—The same machined area after a riser had been removed. (Reduced one-fourth for reproduction.)

Sectioning also may reveal the reason for the defect, whereas, in some cases, X-ray would not. It should be stressed, however, that sectioning is used only as an occasional supplement to X-ray in this plant. X-ray, as compared to sectioning, is considered to be far superior in that it is faster and is non-destructive.

On one occasion, shrinkage was found to be present in a 1½-in. section immediately below a heavier section of approximately 3½ in. X-ray showed this defect present in all current castings. The shrinkage is indicated by arrows in Fig. 16. External chills were used in an attempt at correction.

Checking this practice with X-ray disclosed the fact that the shrinkage had not been eliminated but had moved into the heavier section below (Fig. 17). Chills were then added in the heavy section below, in an endeavor to secure equal rates of cooling and equal solidification. This method of chilling did eliminate the shrinkage (Fig. 18).

In Fig. 19 shrinkage is indicated

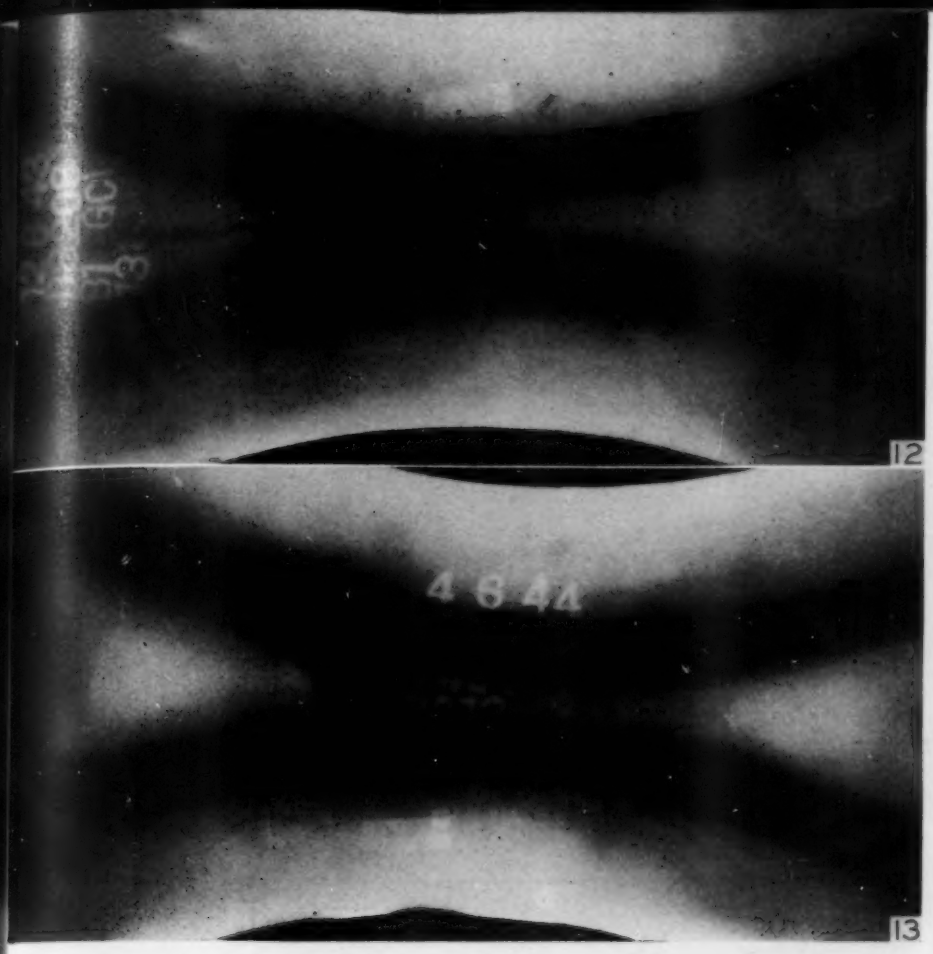


Fig. 12—A 2-in. section with considerable shrinkage. Fig. 13—The same area following a change in design. Fig. 14—Severe shrinkage in a 3-in. section around a lifting lug. Fig. 15—The addition of a feeder produced a sound casting. (Reduced one-fourth for reproduction.)

in a thin and thick adjacent area where holes are to be drilled in the two slots immediately above the heavy section.

External chills were used on the radius of the heavy and thin section, as shown in Fig. 20, but the chills did not remedy the situation and shrinkage is still present.

In the second attempt "bed-in" chills were added in the slots above the heavy section. The chills in the thin section below were omitted and a cracking strip was added in the radius. The shrinkage was not eliminated but moved down into a machined flange (Fig. 21).

The use of "bed-in" chills and a cracking strip (one chill left in slot) and an added external chill in the radius along the machined flange finally cleared up the area, as shown in Fig. 22.

In the foregoing instances, the X-ray made a thorough picture, not merely of the shrinkage but of the surrounding area as well. The first attempts at chilling were ineffectual, as the X-ray disclosed. Instead of eliminating the condition, chilling had moved the shrinkage down into the heavy sections. The pictures showed the need of chills in the heavy sections. This was followed out and additional X-rays disclosed that the trouble had been eliminated.

In comparison to sectioning, this method was faster by days. It was more thorough in that a perfect picture was obtained, not only of the defect but also of the surrounding area, which proved helpful in that the first attempts at chilling had not been misleading.

Shrinkage had not been eliminated, but moved to another area. The X-ray not only pointed out the error but showed the proper places to chill. Then, too, X-ray was cheaper in that all castings were saved, whereas they would have been destroyed in sectioning.

X-ray pictures, because of their thoroughness, are very impressionable. Pictures which show so clearly the actual results of our own efforts

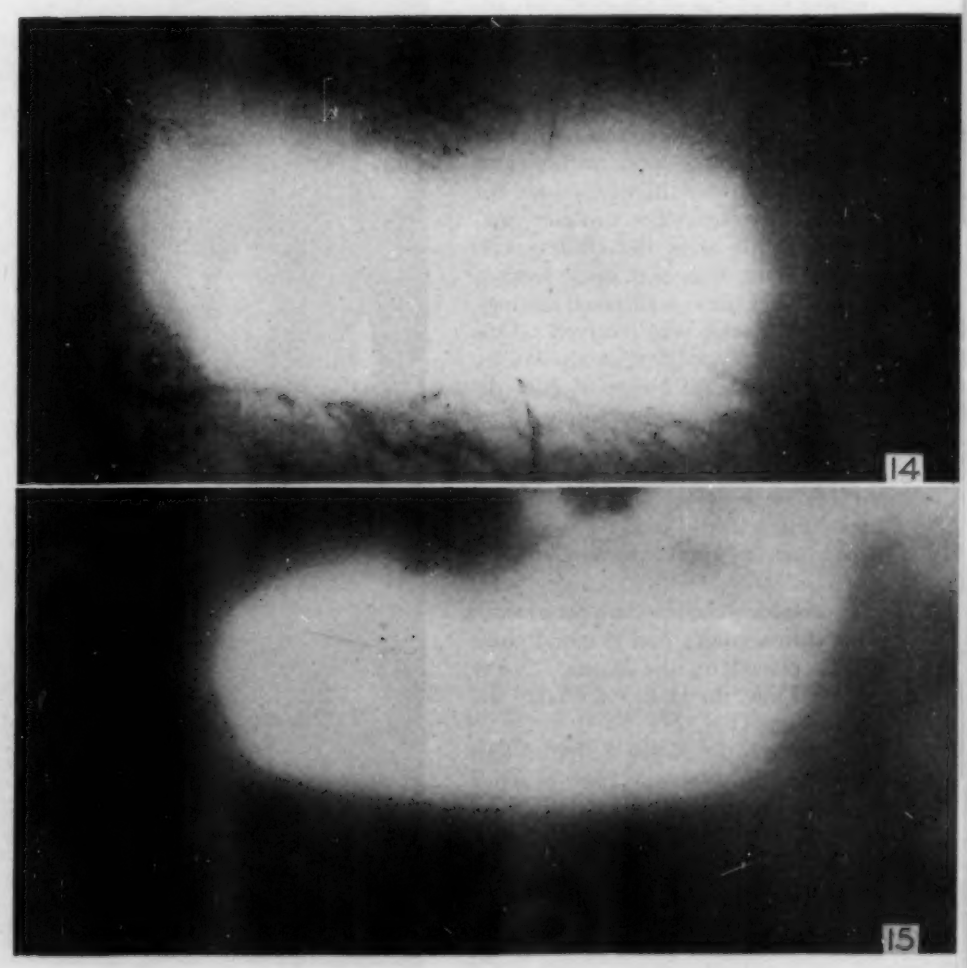


Fig. 16—X-ray reveals the presence of shrinkage in a light section of a casting. Fig. 17—External chills used drives shrinkage, shown in Fig. 16, from beneath heavy section into the heavier section below. Fig. 18—Chills added in the heavy section below, tending to equalize solidification rates, produce a shrink-free casting. (Fig. 16 reduced one-fourth, Figs. 17 and 18 reduced one-fifth for reproduction.)

are not easily forgotten. On the contrary, they are most readily catalogued and filed in our minds for future reference. For instance, several months after the chilling episode of the thin and thick sections of the previously mentioned castings, a new pattern was received. One side wall was approximately 1½ in. thick, with eight bosses of 2-in. diameter and approximately 3-in. thickness.

X-ray disclosed shrinkage above all the bosses (Fig. 23). The foundry superintendent viewed the film. Immediately to mind came the pictures of previous chilling experiments. The bosses were bleeding metal from the thin sections, and external chills were placed on the bosses. X-ray proved that the chills eliminated the shrinkage (Fig. 24).

Through the X-ray a tremendous amount of work on riser practice has been possible. The placing of a complete picture of the interior of a casting before the Planning Committee is a direct challenge. Either the casting has shrinkage and needs additional risers, or some cer-

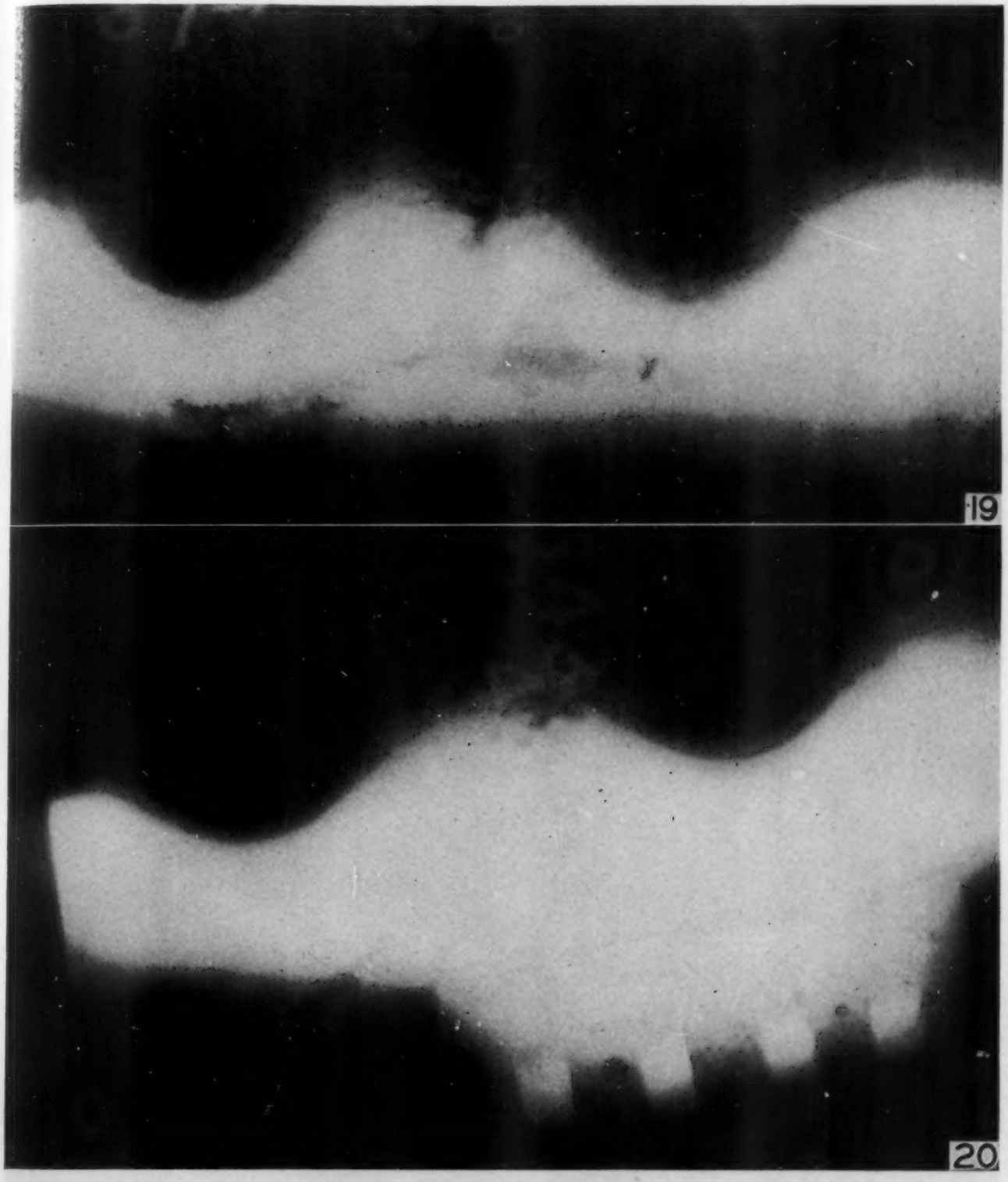


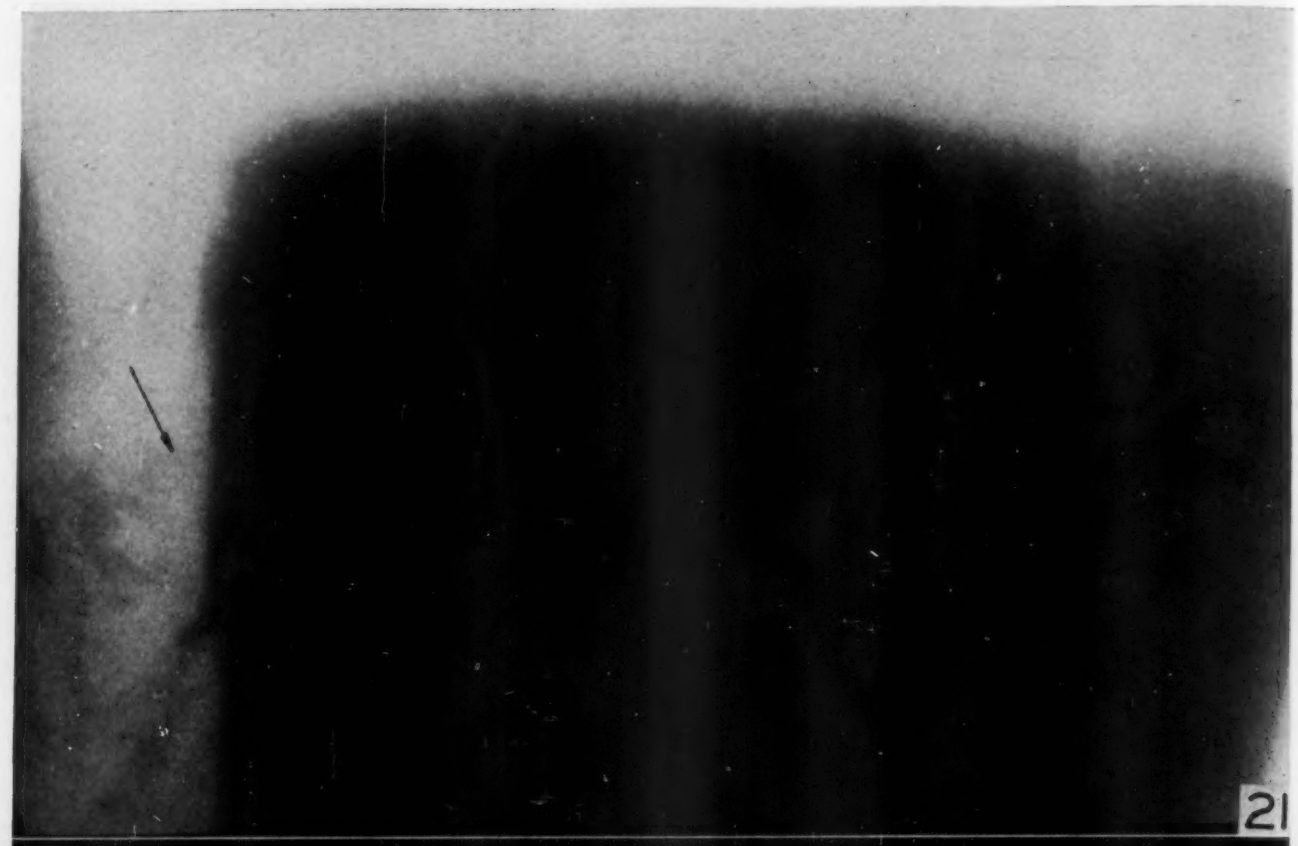
Fig. 19—Shrinkage in a thin and thick adjacent area. Fig. 20—Use of external chills on the radius fails to clear up the condition. (Reduced slightly for reproduction.)

tain riser or risers should be increased in size. Possibly, the casting is solid throughout and risers may be reduced and even eliminated.

The speed with which results have been obtained through the X-ray has made possible the great number of experiments which have been run. Only a small fraction of these experiments would have been attempted had it not been for the X-ray. Through the use of the X-ray, risers have added, relocated, reduced and even eliminated on many patterns, which in turn has made it possible to produce better castings at lower cost.

Some risers are now being X-rayed instead of sectioned, and the results are promising. Risers of up to 7-in. diameter have been X-rayed and good pictures secured. It takes approximately 45 min. to X-ray a riser 7 in. in diameter.

Risers have been X-rayed, then



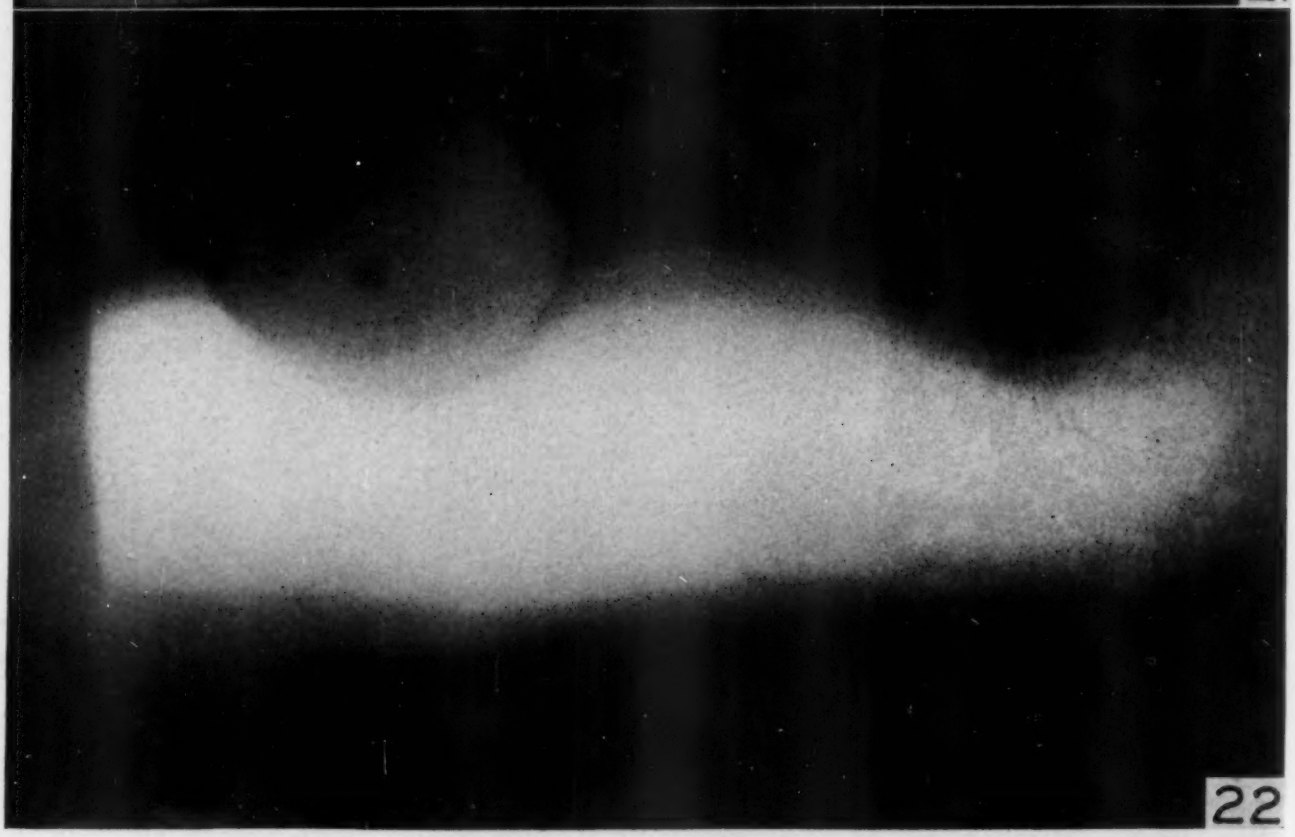
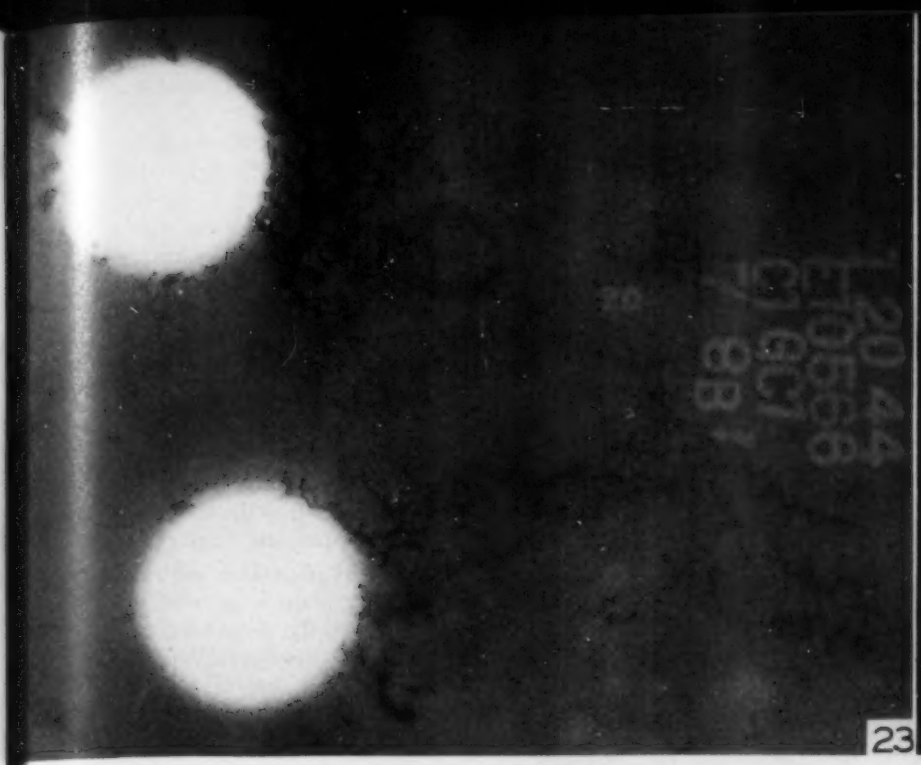


Fig. 21—Another attempt to remedy the shrinkage, shown in Fig. 19, has been made but despite the use of chills and cracking strip the defect can be seen in the machined flange. Fig. 22—Defect eliminated through revised method of employing chills and cracking strip.



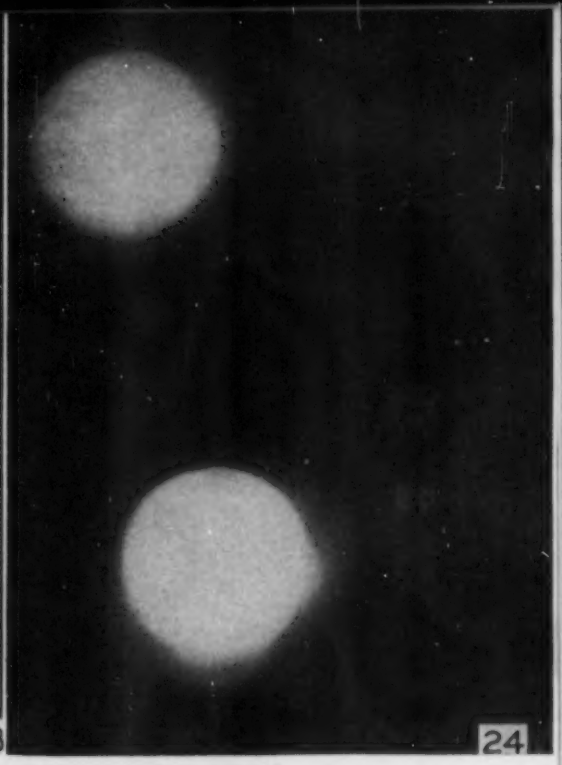


Fig. 23—The presence of shrinkage is detected by X-ray in a section containing two bosses. Fig. 24.—Defect was remedied by placing external chills on the bosses. (Reduced one-third for reproduction.)

sectioned, and the same interpretations of the action of the riser obtained. Sufficient work has not been done to elaborate further, but it is believed to be a promising procedure. It is hoped that the results obtained in sectioning may be obtained in less time and at a lesser cost by the use of X-ray. A typical example of the feeding action of a riser is shown in Fig. 25.

The X-ray has stressed the importance of cores and molds in regard to dirt and gas. Through the X-ray, the necessity of having properly baked cores as well as properly dried molds was learned. A casting weighing approximately 600 lb. and having a ring design with five blind risers and two open risers was poured. Its design did not lend itself to good ventilation and consequently gas troubles were encountered (Fig. 26).

More vents were taken off the mold and the results were not too encouraging. The blows seemed to have been dispersed but not eliminated (Fig. 27). By further investigation considerable variation in the baking of cores was found. Experiments

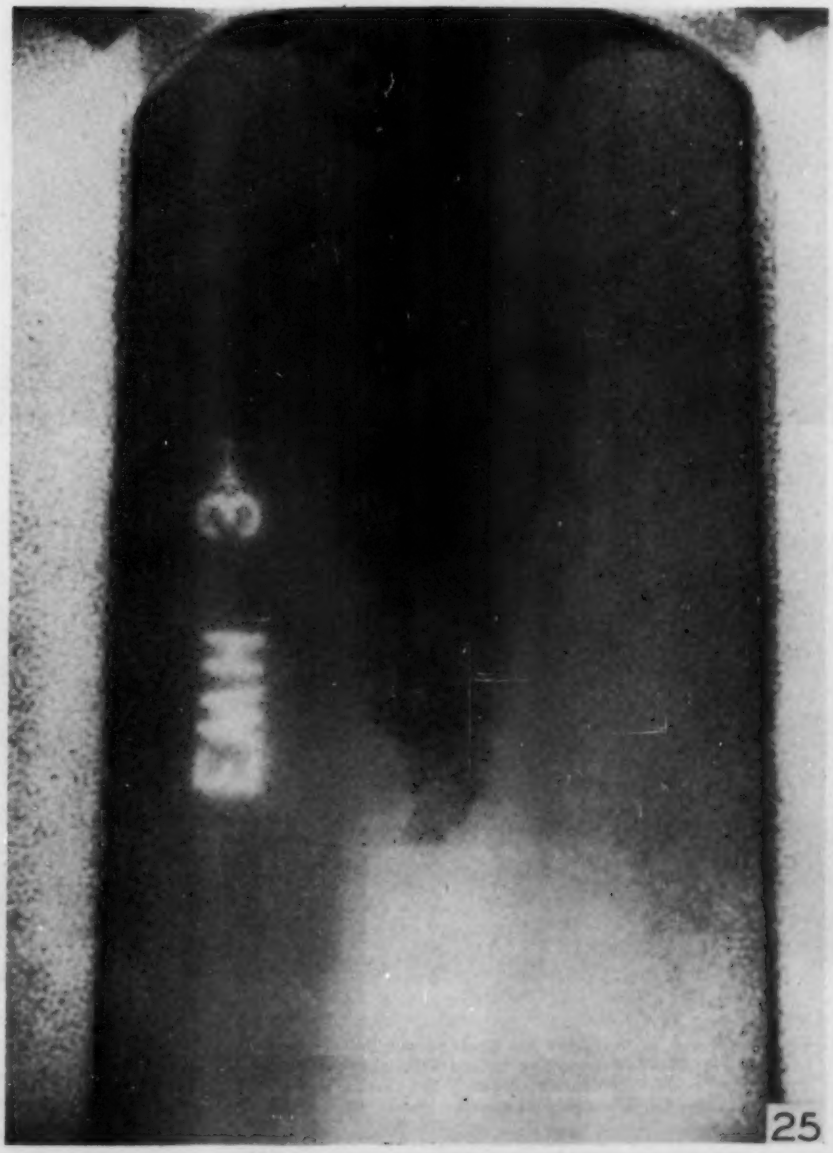


Fig. 25—Feeding action of a 6-in. riser as disclosed by X-ray. (Reduced one-fifth for reproduction.)

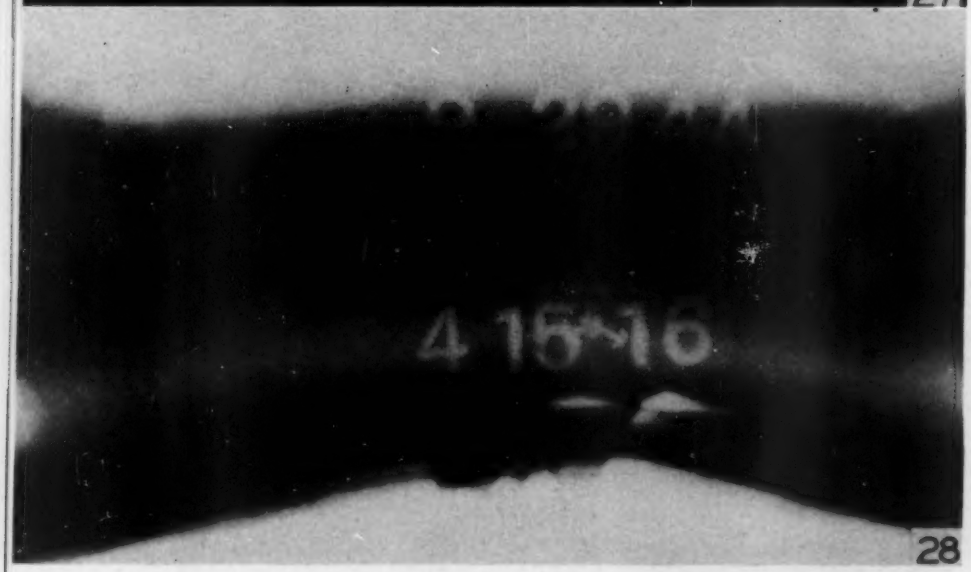


Fig. 26—Arrows in this X-ray are pointing out defects caused by gas in a ring design casting. Fig. 27—Better venting caused little change in the area as defects were only dispersed. Fig. 28—Elimination of gas in the casting was attributed to reduction of gas from the cores by thoroughly baking the cores. (Reduced one-third for reproduction.)

were made with more thorough baking of the cores, which reduced the gas content of the sand in the cores from approximately 35 cu. cm. of gas for a 3-gram sample to less than 20 cu. cm. for a 3-gram sample. The reduction of gas in the cores resulted in eliminating the gas condition in the casting (Fig. 28).

The speed of this test and the fact that the castings were not destroyed made it possible to improve the quality of the castings without increasing the cost, a factor that is always interesting to management.

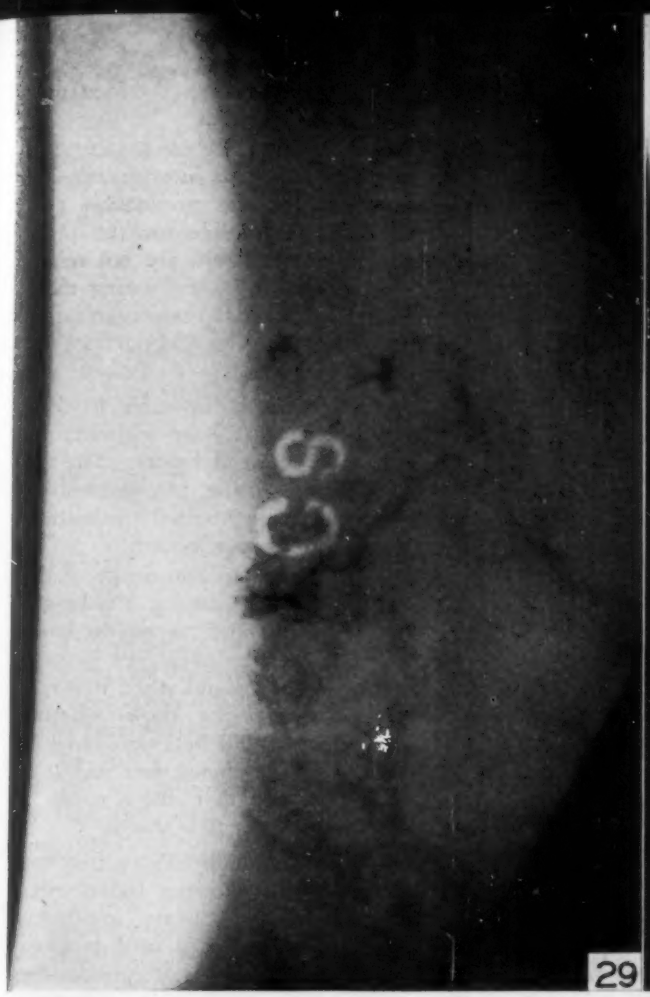
The second important use of the X-ray at this plant is in routine inspection. Once the proper technique and practice is developed, the job is still not finished due to the many variables which occur in the foundry.

We are all familiar with the variation that occurs from casting to casting. These variations are due, in some cases, to factors beyond our control, or due to the human element as well as slight changes in practices, materials, and actual mistakes. By spot checking the castings with X-ray, many of these slight variables are caught before the practice becomes serious enough to affect the quality of the casting. In non-destructive tests, such as the X-ray, both the foundry and the customer are given assurance that the practices are under control.

Development and Inspection

It is interesting to compare the present practices of development and inspection of castings with former practices. On a recent rush job, the casting was poured, heads and gates burned off, some rough chipping done and the casting X-rayed in an elapsed time of 3 hr. 50 min. The X-ray findings being satisfactory, the 450-lb. casting was put into immediate production.

Compare this with previous procedures. For much of the work the casting was given a visual inspection and then a physical test, followed with sectioning the highly stressed areas, or wherever defects appeared in the casting from the physical test. This procedure took several days at least, and sometimes as high as 10 days, before sufficient information was obtained to show whether the pattern should be resampled or whether it could be put into production. If the job called



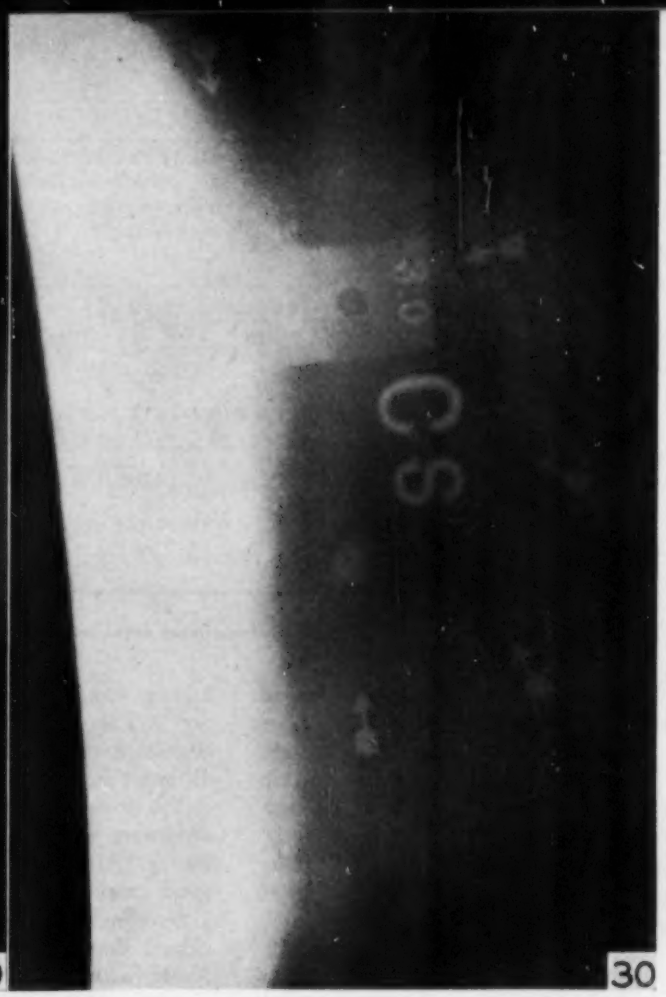


Fig. 29—An X-ray photograph revealing unacceptable shrinkage in a three inch section.
Fig. 30—Same section after shrinkage had been burned out and welded satisfactorily.
(Reduced one-third for reproduction.)

for re-sample, the entire process had to be repeated, resulting in further delay.

If it is believed that there is some chance that the casting will be satisfactory, it is the present practice to pour two samples in order to speed the process. One of these samples is for the inspection department and the other for the X-ray department. The X-ray casting is burned, rough chipped, blasted, and then X-rayed.

Immediately after inspection of films the foundry has a complete picture of the condition, not only of the highly stressed areas but of the entire casting, and is ready to make the necessary changes in technique. This is generally accomplished in something like 48 hours after the casting is poured. The other casting, meanwhile, has been going through the regular procedure, being checked dimensionally by the inspection department.

Another noteworthy use of the X-ray in steel castings is the educational feature, the actual educating of the workmen themselves. In order to do this, meetings of the molders, finishers and coremakers are held. In these meetings are displayed X-rays showing areas of castings that are defective and the same areas after changes have been made correcting the defects. One would be surprised at the interest of each man. The enthusiasm shown by these men in seeing the actual results of their work pays dividends. Here are some comments made by a finisher at one of the meetings: "Now I can understand why my foreman insisted on those chill coils being placed exactly within a certain 6-in. area along that rail. I was angry because I thought that he was showing his authority. Now I see more of the why and wherefore. To get better results the company should show us more X-rays."

Employee Interest

Numerous comments of this type have been made. Their interests have been aroused and suggestions have been made freely by them, a number of which have been useful. Displaying X-rays to these men tends to create a better spirit between workmen and management. It is an immediate aid in the production of better castings.

X-ray pictures have been shown to the welders to illustrate the type of welds being made by them. It is felt that this has been of considerable help (from a quality viewpoint) in that it has assisted the men in improving the quality of their work.

X-ray has been an invaluable asset in the inspection of welded sections that are to have an expensive machined finish. It also is interesting to note that defective castings may be saved by burning out the defective material and repairing them by welding, using the X-ray to show whether or not the welds are acceptable. (See Figs. 29 and 30.)

X-ray also has played its part in proving to casting buyers that it is possible to make welds in steel castings, when necessary, that do not impair the stability of the product.

Experience has shown that cast-

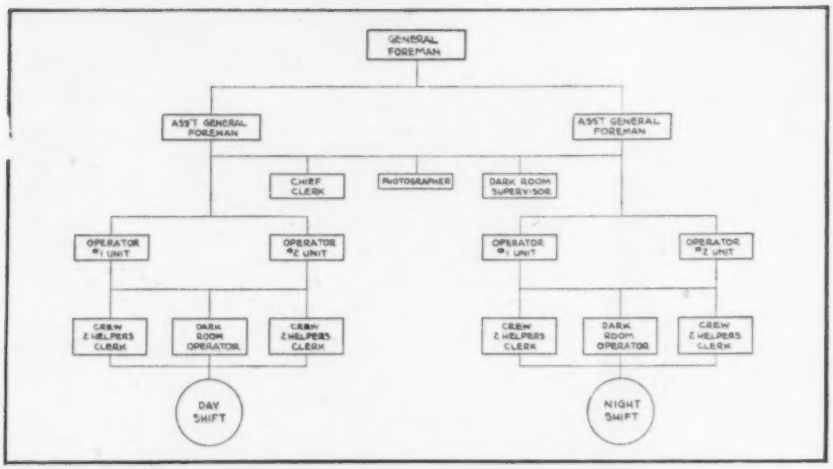


Fig. 31—A typical X-ray department organization chart.

ings need not be entirely free of defects to be serviceable. We have learned through fatigue, static, impact, and ballistic tests that certain defects inherent in castings are permissible in certain sections.

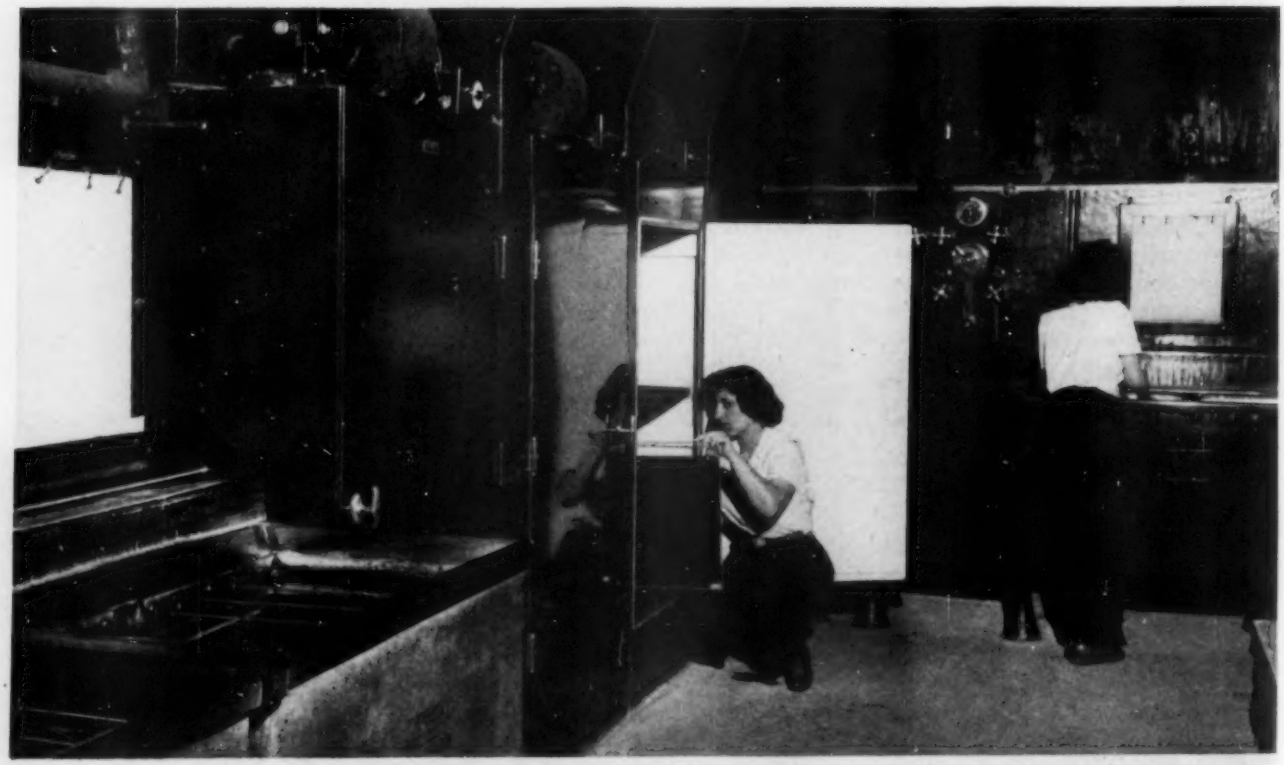
They do not impair the quality or performance of the casting in service. In order to use X-ray intelligently, each casting must be analyzed before being put into production to determine the most critical sections and those which will be subject to the highest stresses. These sections will then be required to pass higher standards of X-ray inspection. The Army and Navy, being cognizant of this fact, have set up different standards for certain areas in the same casting, and these standards may be used as a guide to industry. After all, the criterion of a good casting is performance.

In conclusion it should be mentioned that to get the most out of X-ray without undue expenditures, capable technicians must be employed, having the knowledge to enable them to X-ray a casting quickly and to bring out the defects present therein. Hand in hand with this talent goes proper interpretation of films so that the production men who are responsible for the practices and techniques are not misinformed and make the wrong move in the plant. A typical organization chart of an X-ray department is shown in Fig. 31.

At times it is advisable to combine the use of X-ray with sectioning, as mentioned before. The use of magnetic testing, physical testing, and of course, visual inspection, should not be overlooked.

Experience and knowledge of the use to which the casting is to be put enables a qualified person to know when a defect, as shown in the X-ray, is serious and when it is not. Thus the inspector knows whether the defect should be examined further by one of these other means of testing or whether the casting is satisfactory as it now stands.

Without a doubt X-ray is a tremendous asset to the foundryman in his aim of always improving his product. Also, if used properly it may be the means of considerable savings through the elimination of unsatisfactory castings, quicker inspection and, consequently, less time lost in getting a job into production.



(Photo courtesy American Steel Foundries, Granite City, Illinois.)

Photo of a well organized X-Ray laboratory darkroom.

• ***The relation of amount of metal frozen to time cannot be satisfactorily explained if the conductivity of molding sand is taken as independent of temperature. It is shown that a better correlation can be obtained if the heat transfer within the sand is assumed to be in part by conduction and in part by radiation.***

The Influence of Radiation Within Molding Sand on the **FREEZING RATE** *of Metal*

By H. A. Schwartz, Manager of Research,
National Malleable & Steel Castings Co., Cleveland.

IT HAS been shown by the writer[1] that there is good agreement among reliable workers that for some time during the freezing process the thickness of the frozen layer of steel increases as the square root of the time, but later increases in proportion to the time. That is to say, the time-thickness curve is first a parabola and then a straight line tangent thereto.

This type of curve is qualitatively alike for many shapes and sizes of castings and always represents a rate of freezing faster than can be calculated from the usually accepted thermal conductivity of sand. Nor can the form of the curve, representing an acceleration of the freezing mechanism, be explained by any plausible assumptions.

To throw some light on this subject, the author here offers an admittedly inaccurate solution of a problem not realized in the foundry under hypothetical conditions resting on no direct evidence. He can only justify such rashness by saying that the mathematicians seem unable to furnish an accurate solution. The problem is one which is closely approached during the early stages of freezing of flat-sided objects, and apparently the conditions are maintained for a considerable time in even moderate-sized castings. The problem is, therefore, reasonably simple of attack and a reasonable approach to reality.

It is the purpose of the paper to determine whether the hypothetical conditions are reasonably consistent with the known facts. Be it noted, however, that if they are so consistent this is not proof that they *are* the cause of the observed effects but only that they *may be* the cause. Perhaps other causes could explain the effects, also. Radiation is probably a sufficient explanation of what happens, but not a necessary explanation.

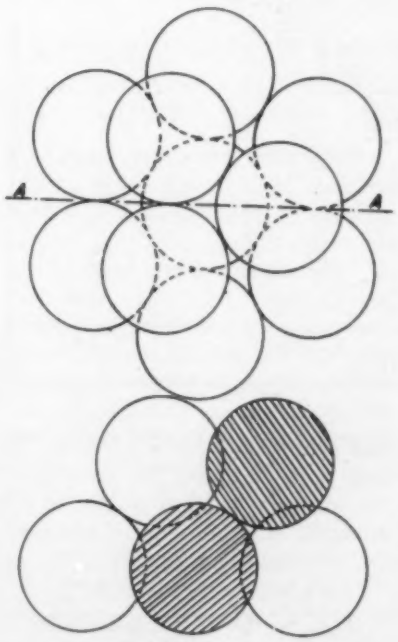
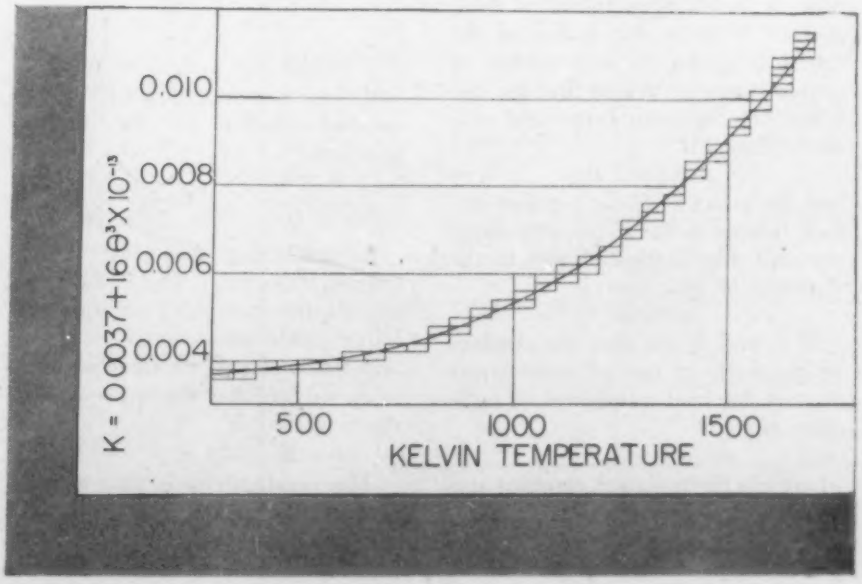


Fig. 1—Above—Close packed arrangement of spheres. Fig. 2—Below—Apparent thermal conductivity of sand as a function of absolute temperature.



We desire to find what is the form of the curve correlating the amount of heat absorbed as a function of time by a semi-infinite body of sand whose surface is suddenly heated by 1400° C. (2520° F.) above an initial uniform temperature of 27° C. (80° F.=300° K.) if the properties of the sand are as follows:

The apparent density (ρ) of the sand as packed is 1.65 gm./cm.^{3}, and the apparent specific heat *(C)* is 0.45 cal./gm., both independent of temperature. The sand consists of uniform spheres one mm. in diam-

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Committee on Heat Transfer of A.F.A.

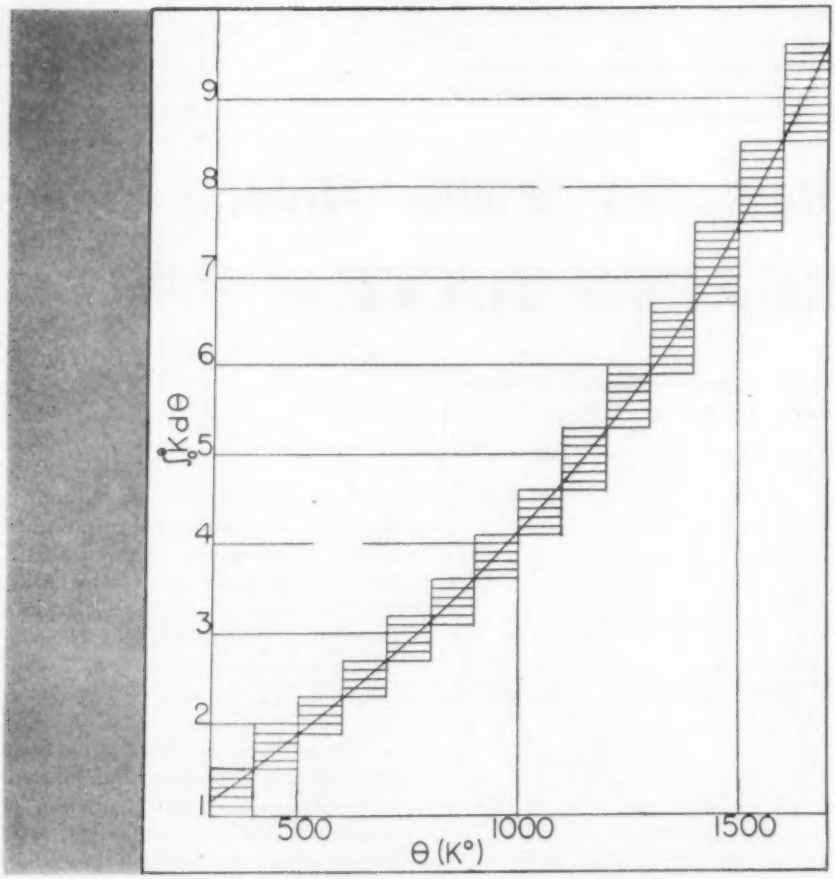
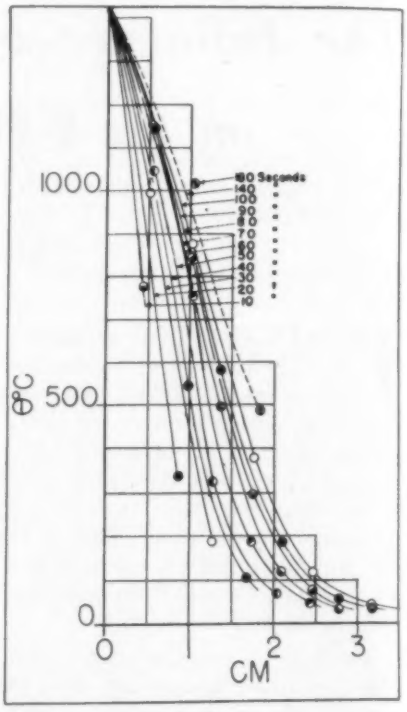


Fig. 3—Left — Chart for determining the mean thermal conductivity of sand.

Fig. 4 — Below — Temperature within the semi-infinite sand body as a function of time and distance.



eter "close packed" in layers at right angles to the direction of heat flow. The apparent conductivity *(k)* at 300° K. is 0.0037 cal. cm.$^{-1}$ sec.$^{-1}$ °C.$^{-1}$ and the sand grains radiate as "black bodies," the highest radiation which can exist. The latter condition is chosen to evaluate the maximum effect.

The postulated arrangement of sand grains is shown in Fig. 1, the flow of heat being taken as horizontal. If R be the radius of the spherical grains, it is a matter of simple geometry to find that the distance *(D)* between centers of successive layers is

$$D=1.632\ R,$$

and the area *(a)* of sand grains surface, facing toward the next layer per unit area at right angles to the direction of heat flow, is

$$a=3.63.$$

If θ_1 and θ_2 are then the absolute temperatures of two adjacent layers of sand, the heat transferred by radiation alone is

$$a\sigma\ (\theta_1^4 - \theta_2^4),$$

where σ is the radiation constant and equal to

5.7×10^{-5} erg cm.$^{-2}$ sec.$^{-1}$ °C.$^{-4}$.

Converting from ergs to calories and substituting for a its value, the heat (cal.) radiated per sec. per sq. cm. of area at right angles to the direction of heat transfers becomes:

$$a\sigma\ (\theta_1^4-\theta_2^4)= 49.368\ (\theta_1^4-\theta_2)^4\times10^{-13}.$$

If k_0 be the true conductivity of the material assumed independent of temperature, then the total heat transferred in one sec. per unit area of cross section

$$\frac{(\theta_1-\theta_2)\ K_0}{D}+ 49.368\ (\theta_1^4-\theta_2)^4\times10^{-13},$$

and the apparent conductivity is this amount divided by the thermal gradient

$$\frac{\theta_1-\theta_2}{D} = \frac{\theta_1-\theta_2}{1.632R}.$$

Remembering that $(\theta_1^4-\theta_2^4)= (\theta_1-\theta_2)\ (\theta_1+\theta_2)\ (\theta_1^2+\theta_2^2)$ and making the reasonably accurate simplifying assumption that $\theta_1=\theta_2=\theta$, and setting for D its value in terms of R, we find that the apparent conductivity *(k)* is

$$K=K_0+324\ R\ \theta^3\times10^{-13}.$$

The conductivity is thus a function of the sand's grain size. For grains having a diameter of one mm., and assuming that at 300° K. the conductivity is 0.0037, we may write approximately

$$K=0.0037+16\ \theta^3\times10^{-13}.$$

The values of K as a function of absolute temperature (θ) are plotted in Fig. 2. In Fig. 3 the area under the curve of Fig. 2 is plotted against θ. The difference between the ordinates of this curve at two temperatures, θ_1 and θ_2 when divided by $\theta_1-\theta_2$ gives the mean value of K in that temperature range.

The general differential equation for the (linear) flow of heat is:

$$\frac{\delta\theta}{\delta t}=h^2\frac{\delta^2\theta}{\delta x^2}$$

where t is time (sec.) and x is distance (cm.).

The solution of this equation for the boundary conditions enumerated in the statement of the problems would be simple if h^2 were constant, but $h^2=\frac{k}{\rho c}$ by definition and, therefore, varies with the temperature. The solution of

$$\frac{\delta\theta}{dt}=\frac{0.0037+16\ \theta^3\times10^{-13}}{0.7425}\ \frac{\delta^2\theta}{\delta x^2}$$

has been impossible for the writer, and also for those consulted who were more skilled in mathematics.

We, therefore, turn to the graphi-

cal Schmidt method as the only recourse. The method has been briefly described by the author in the 1945 Foundation Lecture. For a detailed description consult Sherwood and Reed[2].

The Schmidt method assumes that if time and distance are divided into increments Δt and Δx such that

$$h^2\frac{\Delta t}{(\Delta x)^2}=\tfrac{1}{2}$$

then at a given time a given point will have a temperature equal to the average temperature of the two points Δx on each side of it (in the direction of heat flow) taken Δt previously. The Schmidt solution is a graphic method of plotting, as a function of temperatures at a series of times differing by Δx.

Since $h_2=\frac{K}{\rho c}$, this is equivalent to saying for sand ($\rho=1.65$ $C=0.45$) that

$$\Delta x = 1.842\ \sqrt{K}\ \sqrt{\Delta t}.$$

The time increment is subject to arbitrary choice; 10 sec. was selected for the solution. The conductivity K depends on the temperature and can be approximated rather closely from the conditions Δt earlier. It is thus possible to calculate the value of Δx, appropriate to any time and position. For convenience, the sand, the temperature of which is really a continuous function of x, is assumed to consist of layers 0.5 cm. thick; the temperature of each layer being considered uniform.

The actual graphic solution is too voluminous to be repeated here, but the temperatures at a series of times are plotted against distance below the sand surface in Fig. 4. For convenience, the temperatures have been converted from the Kelvin to the Centigrade scale.

The rate of heat input, per unit area,

$$\frac{dH}{dt}\ \text{is}\ \frac{dH}{dt}=K\frac{d\theta}{dx},$$

where K is the conductivity at the surface which, by assumption, is at 1700° K. or 1427° C. K, therefore, is constant, with time, and from Fig. 2 is equal to 0.0116. $\frac{\Delta\theta}{dx}$ is the slope of the lines of Fig. 4 at $x=_0$ and, of course, varies with the time.

Lines Graphically Determined

The lines of the figures are not reproduced with sufficient accuracy to permit of reading their slopes, but these have been graphically determined from the originals and plotted as points in Fig. 5. The evident scatter is in part due to the inherent difficulties of graphic estimation of the slope of a curving line. A line has been drawn by inspection to show the trend of

$$\frac{dH}{dt}$$

as a function of t. A line has also been drawn showing this relation for the room temperature conductivity of sand. Evidently there is a great discrepancy.

Most notably the present assumptions lead to a locus which seems to reach a constant value of

$$\frac{dH}{dt},$$

while the assumption of a constant conductivity results in a curve which continues to descend, at a decreasing rate, to zero. We can not, of course, be too sure what the observed trend line would do if indefinitely prolonged.

The line marked $K=0.0070$ is the best fit for our complex locus, assuming a constant "apparent" conductivity, and does not fit the observations at all. We can not, therefore, approximate the effect of changing conductivity by the use of some average value. Quite empirically the locus put in by inspection conforms with no important discrepancies to

$$\frac{dH}{dt}=\frac{94.2}{\sqrt{\pi t}}+0.000036\quad(60-t)^3\qquad(\text{for}\ \frac{\Delta H}{dt}>6.0).$$

The term $\frac{94.2}{\sqrt{\pi t}}$ represents the calculated value of $\frac{dH}{dt}$ if $K=0.0061$. The right half of the equation could

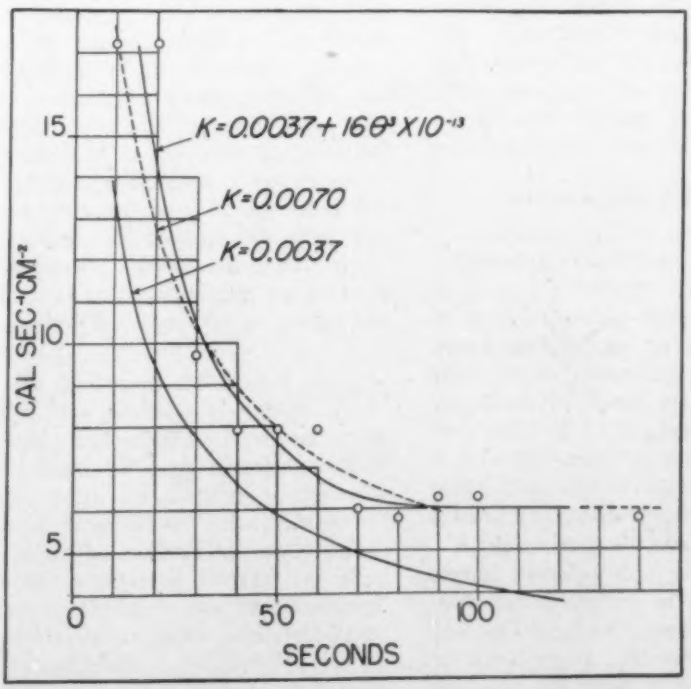


Fig. 5—Rate of heat input into a semi-infinite sand body as a function of time.

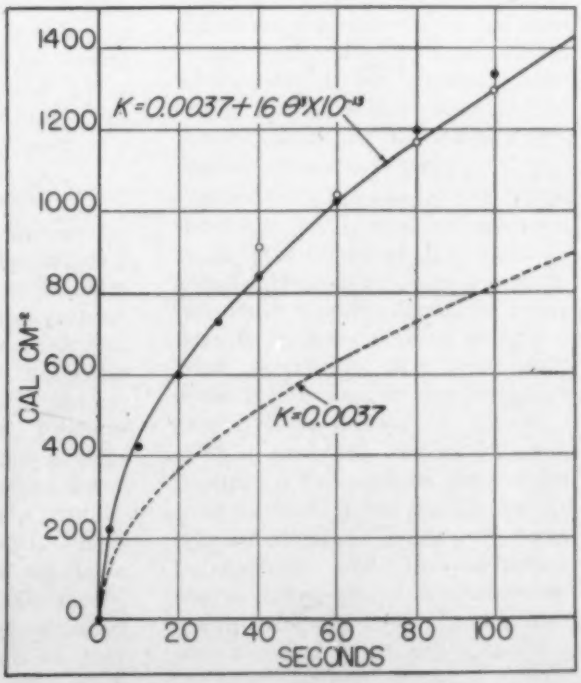


Fig. 6—Heat absorbed by semi-infinite sand body as a function of time.

be recast as a multiple of $\frac{1}{\sqrt{\pi t}}$ and, from the value of that multiple and the known ρ and c, the "apparent" value of K as a function of t derived, but this would yield no information not contained in the above empirical equation, for the "apparent" value of K would only be another empirical means of expressing the same thing.

Computation of Heat Absorbed as Function of Time

Evidently the heat absorbed in time t by the sand will be

$$H = \int_0^t \left[\frac{94.2}{\sqrt{\pi t}} + 0.000036\ (60 - t)^3\right] dt$$
$$= 106.4t^{1/2} - 9(60-t)^4 \times 10^{-6} + 125.6$$

provided $\frac{dH}{dt} > 6$.

Thereafter $\frac{dH}{dt} = 6$ and $\Delta H = 6\Delta t$. One refrains from solving the expression for $\frac{dH}{dt}$ for t if $\frac{dH}{dt}$ be 6 as a laborious piece of pedantry and lets the graphic solution suffice.

In Fig. 6, H is plotted in terms of t as derived from the foregoing equations.

For comparisons the values of H corresponding to the conventional value 0.0037 for K are plotted as a dotted line. The dots of Fig. 6 fall on a parabola ($t = 0.000057H^2$ approximately) and the circles are a straight line. Note first that the curve computed from $K = 0.0037 + 16\ \theta^3 \times 10^{-13}$ passes through a combination of the dots and circles within the errors of the method, and that the heat absorbed in a given time with the variable K is, except at the origin, considerably greater than that for the constant room temperature K. Both of these observations qualitatively confirm the observations on bled castings. The parabola corresponds to a constant value of $K = 0.0098$.

It seems that our calculations probably predict somewhat faster freezing than is usually experienced, and also place the point of tangency of parabola and line at too early a time. Both of these discrepancies could arise from overemphasis on the contribution made by radiation. Purposely, the highest reasonable contribution was chosen, and very likely the sand grain size and/or the emissivity were overestimated.

Conclusions

It seems that the published data on rate of freezing of castings agree better with the assumption that the conductivity of sand varies with its temperature than with any constant conductivity.

They agree, in form, with the type of relation of conductivity which would result if the relation of apparent conductivity and temperature is that which would result if radiation within the sand body determined this relation.

The transfer of heat by radiation is probably quantitatively somewhat less than that assumed in this paper.

References

1. H. A. Schwartz, "How Fast Do Metals Freeze?" *The Foundry*, Dec., 1944, p. 80.

2. Sherwood and Reed, *Applied Mathematics in Chemical Engineering*, McGraw-Hill, New York, 1939, p. 241.

"PHOTO POSITION FINDING"

A Time Saving, Money Saving Method of Communication

By A. C. Kalk, Continental Motors Corp., Muskegon, Mich.

• A method for accurate description and transmission of casting discrepancy information has been developed by the author and is described in the paper. Working photographs illustrate the method.

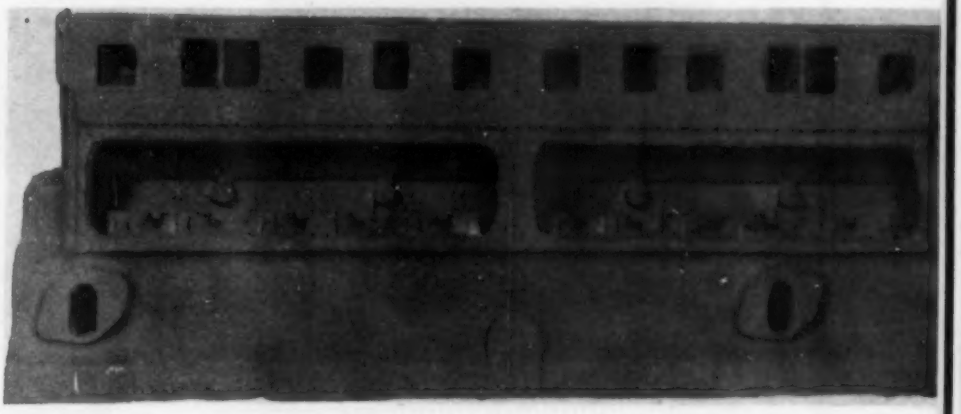


Fig. 1—Cylinder block casting.

IN THE past 25 years, foundry methods for fabricating castings have been improved considerably through science and the use of laboratories, to the extent that today foundries are able to produce quality castings by means of mechanical devices and, in some cases, without the experience of an old-time molder.

There is one problem with which all foundries have been confronted. In the author's mind, it is the most important of all—namely, close contact between a foundry and its customer on production problems. Any solution of the problem involves the finding of a method of communication between the purchaser and the producer of castings whereby the producer may be informed immediately and intelligibly regarding foundry discrepancies or imperfect castings.

By such a means of communication, the producer should be thoroughly informed, by letter, wire, or telephone, of any discrepancy that may occur on castings at the machine shop, when the difficulty results in the castings being rejectable to the producing foundry, so that the discrepancy can be corrected quickly before more imperfect castings are made.

The author has spent several years in the foundry business, and is well aware of the fact that there is no profit in rejected castings.

Prior to the outbreak of the war, users of castings made it a practice to purchase castings from foundries nearest to them, whenever possible. Today it has been necessary to procure castings sometimes at a distance of several hundred miles.

This presents the importance of notifying foundries as soon as possible regarding casting troubles, so as to eliminate the loss of several thousand parts that might be in transit and castings awaiting shipment at foundry to purchaser.

Informing the Foundry

An Example—Let us take an example of this condition. Purchaser *A* is procuring castings from Foundry *B* that is located 800 miles away. Purchaser *A* has an inventory of 1000 pieces. Foundry *B* has three shipments in transit which amount to a total of 1500 pieces. Foundry *B* has 100 castings awaiting shipment. Foundry *B* has a capacity of casting 500 pieces per day.

Assume that Purchaser *A* finds several castings that are rejectable from his inventory of 1000 pieces, due to imperfect castings furnished by Foundry *B*. It would be very costly to Foundry *B* if production were not stopped and necessary corrections made to overcome the difficulty immediately.

On the other hand, Purchaser *A* would suffer if production was stopped by Foundry *B*, because the assembly line using these castings could not continue to operate if castings were not forthcoming daily to Purchaser *A*.

There are a number of ways by which a foundry can be informed of difficulties encountered by the purchaser. Purchaser *A* could explain to Foundry *B* by telephone, telegraph, letter, marked drawing, returning casting, or by sending a representative to the foundry.

With the exception of the latter, the other means of communication could be misunderstood, and serious complications could enter the problem which might result in the rejections to Foundry *B* being of such a large percentage that any profit made in the past on the particular casting would be lost.

This probably would cause Foundry *B* to withdraw the pattern from production and perhaps return it to Purchaser *A*. If this were done, Purchaser *A* would likewise suffer, due to curtailment of production on a unit using the casting and to the time involved in finding a satisfactory new casting source.

If a representative were sent to

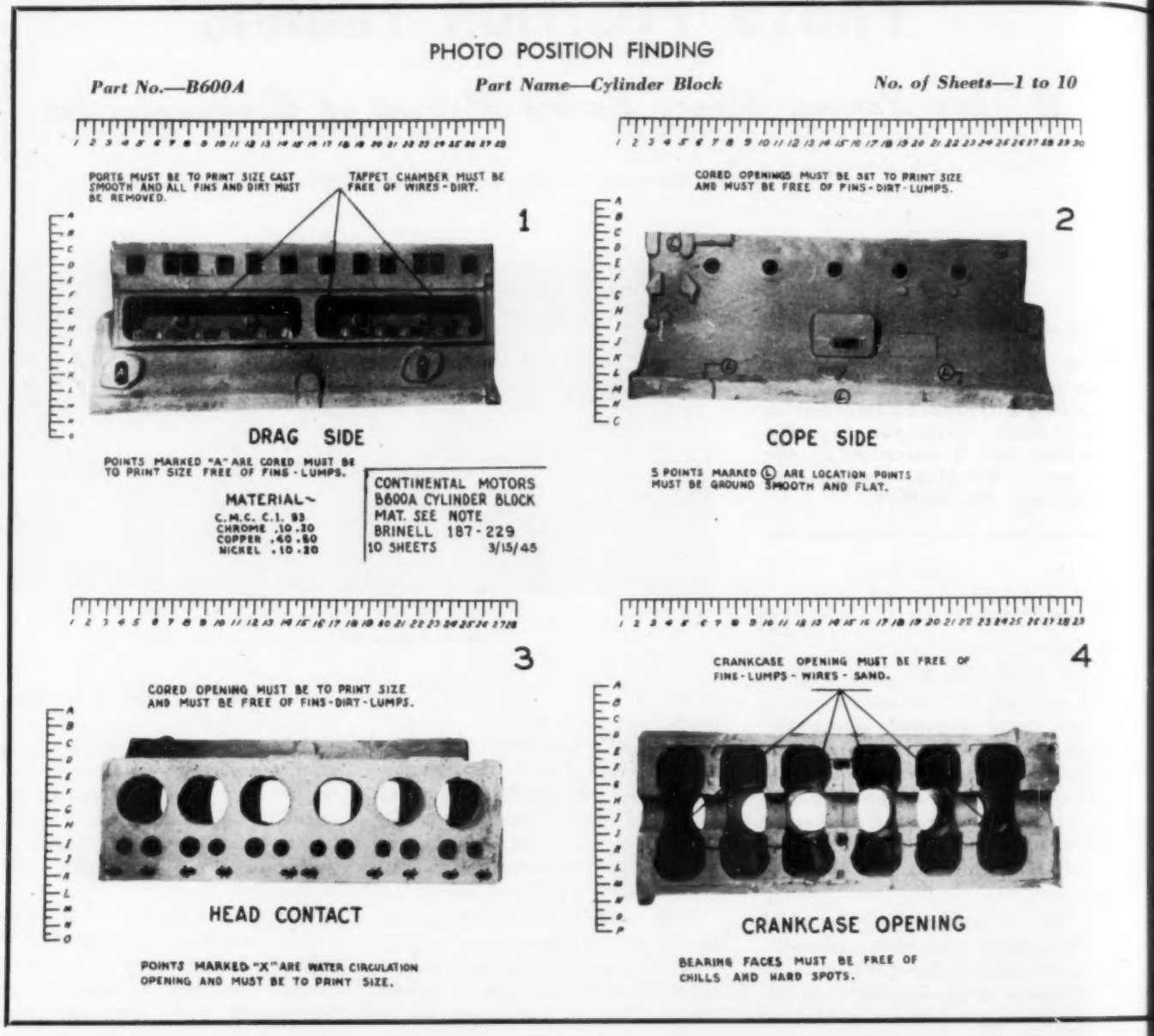


PHOTO POSITION FINDING
Part No.—B600A
Part Name—Cylinder Block
No. of Sheets—1 to 10
PORTS MUST BE TO PRINT SIZE CAST SMOOTH AND ALL FINS AND DIRT MUST BE REMOVED.
TAPPET CHAMBER MUST BE FREE OF WIRES - DIRT.
1
DRAG SIDE
POINTS MARKED "A" ARE CORED MUST BE TO PRINT SIZE FREE OF FINS - LUMPS.
MATERIAL -
C.M.C. C.I. 83
CHROME .10 .20
COPPER .40 .60
NICKEL .10 .20
CONTINENTAL MOTORS
B600A CYLINDER BLOCK
MAT. SEE NOTE
BRINELL 187 - 229
10 SHEETS 3/15/45
CORED OPENINGS MUST BE SET TO PRINT SIZE AND MUST BE FREE OF FINS - DIRT - LUMPS.
2
COPE SIDE
5 POINTS MARKED Ⓛ ARE LOCATION POINTS MUST BE GROUND SMOOTH AND FLAT.
3
CORED OPENING MUST BE TO PRINT SIZE AND MUST BE FREE OF FINS - DIRT - LUMPS.
HEAD CONTACT
POINTS MARKED "X" ARE WATER CIRCULATION OPENING AND MUST BE TO PRINT SIZE.
CRANKCASE OPENING MUST BE FREE OF FINS - LUMPS - WIRES - SAND.
4
CRANKCASE OPENING
BEARING FACES MUST BE FREE OF CHILLS AND HARD SPOTS.

Foundry *B* to explain the discrepancy thoroughly by personal contact, time would be lost in his traveling, for it may take several days for him to reach his destination.

As controller of quality of all castings used by the Continental Motors Automotive Plant, Muskegon, Mich., the author is well acquainted with numerous examples of controversies between casting buyers and producing foundries. We, at the author's company, for a number of years have tried our best to advise foundries furnishing castings to us regarding the nature of a particular casting discrepancy as soon as it would present itself, by various methods.

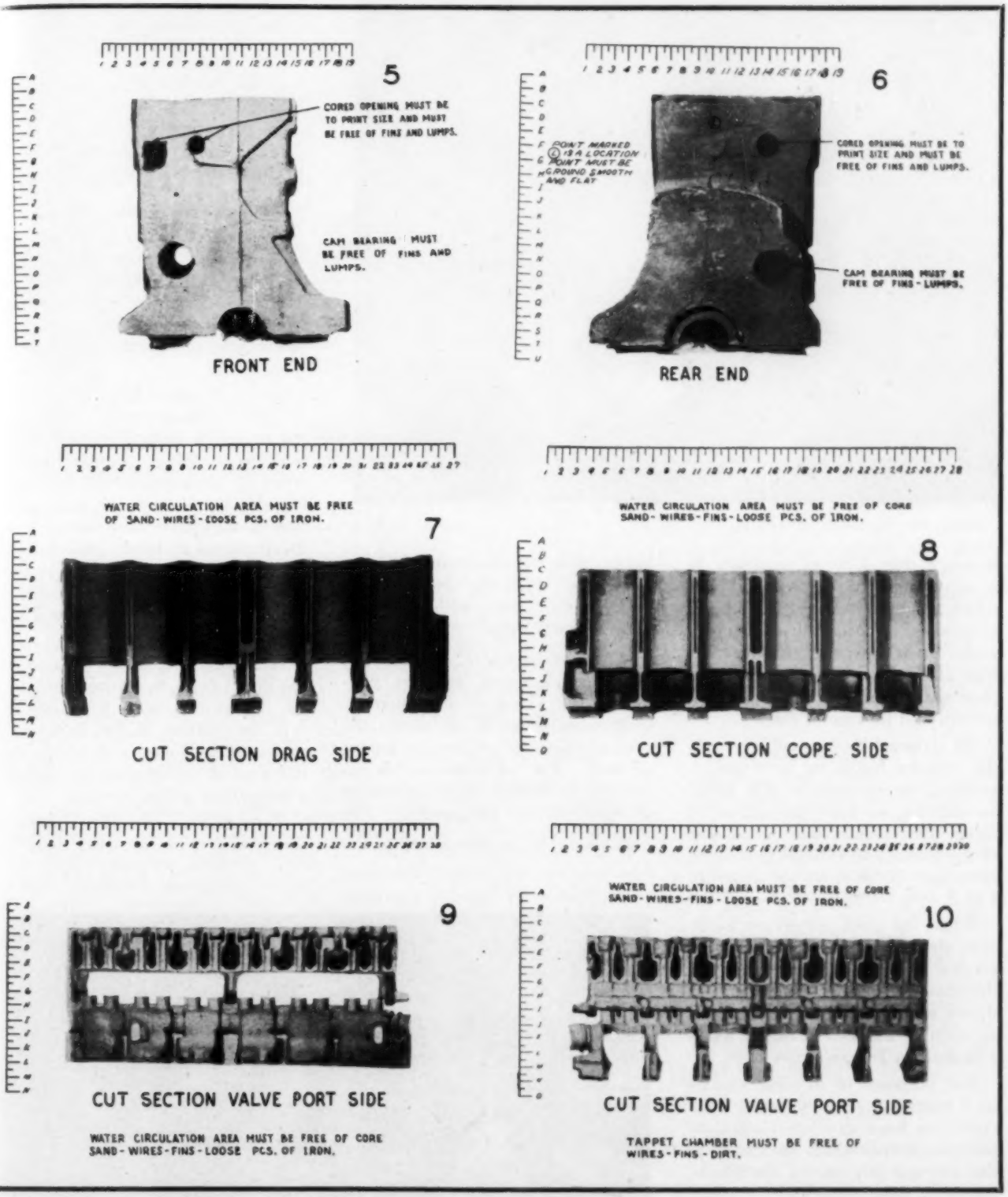
Through years of experience we found no one method of communication was thorough enough for the foundry, in each and every instance, to thoroughly understand the nature of a given discrepancy. Thus, it was necessary for us to devise a system whereby the foundry could be informed of the exact position or location of trouble occurring in castings.

This, of course, can be done by marking blue prints, making sketches, or actually taking photographs of a defective part. However, this material must be presented in some way to the foundry, and time is involved.

It is no disgrace for a person not to be able to read a blueprint, and yet, without photographing or making a sketch of the part, there is no other means of pointing out, mechanically on paper, the exact position or location of a casting trouble.

We have also noted, through past experience, that some foundries criticize the inspection department of a company which buys castings from them. Foundrymen will say, "We had no knowledge that this point was a point of location or that the intake area of that manifold had to be free of fins and dirt."

This misunderstanding is costly, and by no means conducive to a happy relation between the parties involved. To remedy this situation, we have conceived an idea that covers all inspection requirements on castings in such a manner that there is no reason for foundries to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CORED OPENING MUST BE TO PRINT SIZE AND MUST BE FREE OF FINS AND LUMPS.
CAM BEARING MUST BE FREE OF FINS AND LUMPS.
FRONT END
6
POINT MARKED ① IS A LOCATION POINT MUST BE GROUND SMOOTH AND FLAT
CORED OPENING MUST BE TO PRINT SIZE AND MUST BE FREE OF FINS AND LUMPS.
CAM BEARING MUST BE FREE OF FINS - LUMPS.
REAR END
WATER CIRCULATION AREA MUST BE FREE OF SAND - WIRES - LOOSE PCS. OF IRON.
7
CUT SECTION DRAG SIDE
WATER CIRCULATION AREA MUST BE FREE OF CORE SAND - WIRES - FINS - LOOSE PCS. OF IRON.
8
CUT SECTION COPE SIDE
9
CUT SECTION VALVE PORT SIDE
WATER CIRCULATION AREA MUST BE FREE OF CORE SAND - WIRES - FINS - LOOSE PCS. OF IRON.
WATER CIRCULATION AREA MUST BE FREE OF CORE SAND - WIRES - FINS - LOOSE PCS. OF IRON.
10
CUT SECTION VALVE PORT SIDE
TAPPET CHAMBER MUST BE FREE OF WIRES - FINS - DIRT.

Fig. 2—Complete series of photographs on this and opposite page showing all views of cylinder block with inspection requirements noted on each view together with important points of inspection.

be without necessary knowledge of what is required for the production of a particular casting.

In conjunction with this idea, we are able to pass on information to foundries, accurately and understandingly, and to point out to any layman the exact location of a discrepancy. We term this method "Photo Position Finding."

We feel so much confidence in "photo position finding" that we believe it will be accepted by foundries and buyers of castings, because of its universal understandability.

To thoroughly explain "photo position finding" procedure, we will use a cast iron cylinder block, as

Fig. 3—Draftsman lettering necessary inspection requirements on one view of the cylinder block casting.

shown in Fig. 1, as an example. It is a complicated casting and one which might be classed as difficult to produce, especially by a foundry without wide experience with that type of casting. The first step is to photograph the casting from top, bottom and its various sides.

To thoroughly show all views of the cylinder block, we have photographed the six sides of this block. In addition, we have cut sections of jacket and cylinder bore areas, and of the intake and exhaust port valve openings. These views are shown in Fig. 2.

When the photographs are available, the necessary information concerning inspection requirements for the various parts of the casting, as shown on a given view, are lettered on each of the views. Fig. 3 shows a draftsman lettering one view.

For purposes of locating exactly on a casting a given defect or difficulty, we have developed standard positioning lines which are affixed at the top and left side of the photograph, as shown in Fig. 2.

The horizontal line at the top of the photograph is the length of the image and is numbered 1, 2, etc., with half lines between each numeral. The vertical line to the left of the photograph is as long, or longer, than the maximum height of the image. Bisecting lines are lettered A, B, C, etc., with half lines between each letter.

When all views of casting have been photographed, position lines affixed and necessary inspection requirements lettered on them, the originals are photographed in groups of four. The photographer is instructed to furnish a given number of copies of the photographs.

Photographs are distributed to the inspector of the plant purchasing casting, to the department head making contact with foundry furnishing casting, and to the foundry making the casting.

"Photo Position Finding" Operation

This is how "photo position finding" operates. Assume that a blow hole, Fig. 4, is found in a sufficient number of castings to cause their rejection to the foundry and to present a serious difficulty to the purchaser.

Let us designate the purchaser as *A* and the foundry as *B*. Purchaser *A*'s inspector finds the defect and refers to his "photo position finding" series of photographs for the casting. He then locates the exact position of the defect and reports it to the department head, who in turn verifies the location, as shown in Fig. 5. Please note that the defect shown in Fig. 4 is located at position D-13 in Fig. 5.

Following the exact location of the defect by both the inspector and the department head, the latter relays the position of the defect and its nature to Foundry *B*, which also has a set of "photo position finding" photographs of the casting.

Transmitting the Information—Telephone, wire or letter may be

Fig. 4—Inspector pointing out large blow hole on manifold contact of cylinder block casting. The defect was not visible on the rough castings.

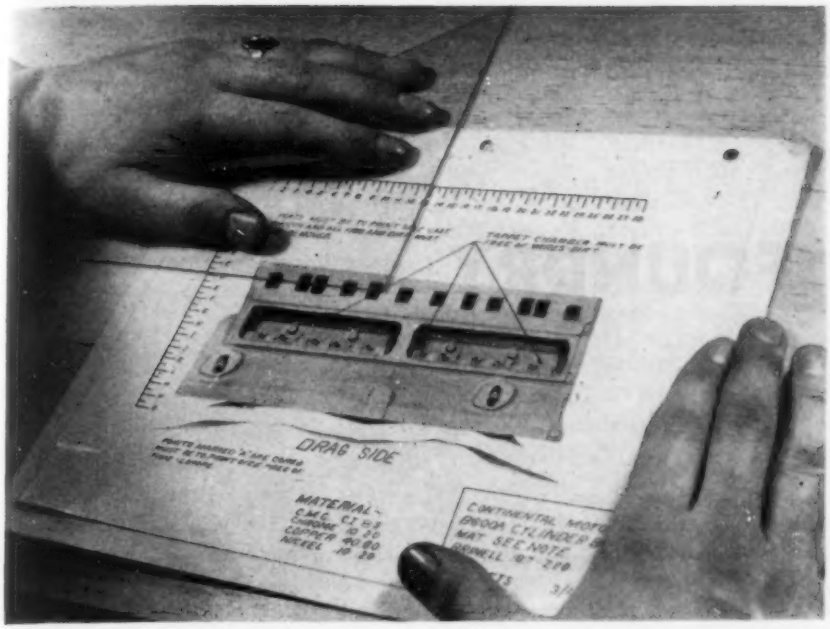


Fig. 5—Locating exact position of defect shown in Fig. 4 on photo position finding sheet before reporting location to the foundry. Position as noted is D-13.

used to transmit the position and nature of a defect. The facility chosen would depend on the seriousness of the condition.

The information transmitted to Foundry *B* should contain the following items to enable the foundry to locate exactly the difficulty involved on its "position" photographs:

1. Part number or casting symbol number.

2. Sheet number showing particular "position" photograph to be discussed.

3. Defect position (D-13, Fig. 5).

This information can be transmitted very easily to foundries by code by any of the facilities mentioned previously.

Foundry Receives Information—Foundry *B*, upon receipt of the information, locates the position of the difficulty on the proper photograph and relays this message to foundry department which this discrepancy may concern. Steps then can be taken to correct the foundry practice to eliminate the defect with minimum loss of production.

The method outlined above has been used by the company with which the author is affiliated with great success to save time and money on both its own part and that of producers from which it purchases castings. One of its outstanding advantages is that the method promotes good relations between buyer and seller—an important consideration in any business.

Advantages of Method

Photo position finding has a number of advantages in addition to those of exactly locating an error in a casting in a thoroughly understandable manner without mailing a drawing, submitting a casting or sending a representative to the producing foundry. These are:

1. The foundry or manufacturer of any particular item is acquainted, at all times, with the inspection requirements, because each view or photograph has its inspection requirement clearly printed on it and particular points are legibly marked. This eliminates controversies between the producer and purchaser of any commodity.

If the part purchased is sound and free of internal discrepancies and the producer abides by the inspection requirements on photo, there should not be any reason for misunderstanding what the purchaser expects as a commercial casting or commodity.

2. On parts that require chaplets, some foundries are today making notations on the backs of their photographs, detailing the position where particular size chaplets are to be used. The advantage of those notes is that when the patterns for the parts are put into production, errors, such as using chaplets of improper size or using proper size chaplets in wrong locations, will not occur.

3. Patterns that do not run regularly in the foundry are easily found in the pattern storage by first looking at photographs to gain knowledge of what pattern or casting looks like.

4. Photographs can be used by the foundry to refer to requested changes in the design of a casting. By referring to location of the desired change on the photograph or by placing a sheet of transparent paper over photograph and marking changes on it, the foundry can transmit its desires to the purchaser very easily.

If the latter method is used, in addition to marking the corrections, the locating lines at top and left of the photograph should be marked on the transparency. After the part number and photograph sheet number have been added, the transparency can be mailed to the purchaser.

Upon receipt of transparency, all purchaser need do is to use this photograph in conjunction with horizontal and perpendicular lines, marked on transparent sheet furnished by foundry, and the exact location of change requested by foundry can be found on photograph. This is very easily explained to the engineering department by the purchaser, and lost time is definitely eliminated.

Conclusion

There are an unlimited number of possibilities and uses of "photo position finding." The idea was conceived for castings and foundry purposes. However, this method of communication between two or more parties could be used on practically any part manufactured where close contact between purchaser and producer is necessary.

PATTERNS . . . *in the* JOBBING FOUNDRY

A well-made pattern, designed for practical foundry procedure, enables the foundryman to produce a better casting at lower cost. Jobbing foundries, handling a variety of patterns, find that close cooperation with the patternmaker will solve many production problems, preserving the castings' advantages over competitive processes.

W. C. Manwell
President and General Manager
M. B. M. Foundry Co.
Cleveland, Ohio

DESIGNERS OF EQUIPMENT work on theory, modified by practical experience. If this procedure were followed in pattern planning for foundries, better and more practical patterns would result. Unfortunately, the men who build patterns seldom have the opportunity to use them. They have little opportunity of learning to avoid in pattern design that which is learned from foundry experience.

The author has accumulated the experience of "old timers" who have used many thousands of patterns in many jobbing foundries and wishes to summarize their experiences and observations.

The company with which the author was associated normally had a changing pattern-flow of over 1000 patterns per month. Among these patterns may be found many types and variations, as the castings made weigh from a few pounds to 20 tons or more. Castings are made in green sand, dry sand, and loam, so the author's experiences are based on a wide variety of pattern requirements for jobbing work. To the experience in his present company can be added that obtained in many other foundries over a period of more than 40 years.

Some general statements can be made before beginning a detailed analysis of the practical problems in pattern design. In the first place, when there is consistent trouble with a casting, it usually is due to improper pattern design. This is particularly true when the castings have poor appearance or inaccuracies.

Improper pattern design also is responsible for certain other casting defects. Therefore, it may be said that an impractical pattern gives poor and costly castings. Conversely, a well-made pattern, designed for practical foundry procedure, usually gives a *better* casting at *lower* cost. It is the purpose of this discussion to point out some of the practical problems in foundry operation, related to patterns, which have a serious effect on both quality and cost. The considerations will be covered in detail and then summarized.

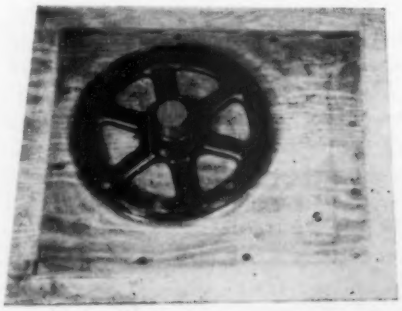
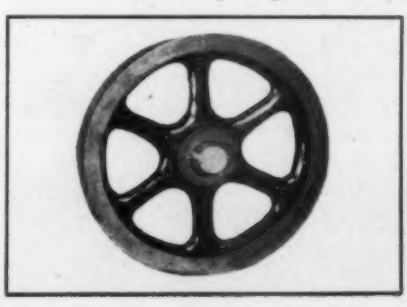


Fig. 1—Photograph (below) shows that, if a solid pattern is used, a match must be made to give a parting or the molder must cut a parting. If the pattern is split (above), it can be molded off a flat molding board or mounted permanently with permanent gating.



With a few exceptions, there is no justification for ever making a solid pattern because it is always better to work off a flat or straight mold parting. This is true from the standpoints of molding economy and appearance. To explain the foundry advantage of split patterns, let us analyze the way in which they can be used.

Reduce Required Molding Skill. If a molder has a split pattern, he does not need a match (Fig. 1) or a false cope from which to work. Nor is he required to bed-in the pattern. He simply lays the drag part of the pattern on a flat board, puts on the drag part of his flask, rams it, rolls it over and proceeds with the cope. He has no partings to make. Time is saved. Less skill is required. This simple principle of working off a flat parting should be followed even to the extent of using a core to keep the joint of the mold on a straight line.

Reduce Mold Patching. If a solid pattern is used, it has to be coped-off, which may mean patching. With the pattern split, this can be avoided.

Reduce Molding Cost. If a solid pattern is used, the rapping pin and draw screws must be used right on the face of the pattern. This soon roughs the pattern or puts holes in it. It then becomes necessary to patch all molds after a few have been made, thus making it almost impossible for a molder to produce neat castings. As patching slows up molding, costs increase (Fig. 2).

Facilitate Delivery. Split patterns

Fig. 2—A solid pattern after short foundry use. Note how face of pattern has been marred by use of a rapping bar.

make good production possible with less skill on the part of the molder. Therefore, they expedite deliveries and save defects to the customer. In every foundry, only certain molders have the patience and skill to take the necessary care with a mold when solid patterns are used. If the foundry is busy, this means that production of molds made from solid patterns must wait until one of the more skilled molders is available. This is not satisfactory, either to the foundryman or the buyer.

Patterns Mounted for Small Orders. Split patterns can always be mounted on a pattern plate, if the quantity of castings required justifies it. As jobbing foundries more and more are adopting production foundry methods, this is of utmost importance. This adaptation cannot be made with a solid pattern. As an illustration, in using split patterns, this foundry regularly mounts them on pattern plates for quantity requirements of ten castings, and sometimes less. This enables production to be improved by the molding machine method.

The pattern draw is improved by the use of a vibrator, and planned permanent gates can be used. This eliminates the necessity of the molder cutting the gates. All of these points benefit both the foundry and the buyer. The foundry's molding and cleaning costs are reduced and the buyer gets better castings at a lower price. Figure 1 (left) shows a split gear blank pattern which has been mounted on a board.

Pattern Loose Pieces

There are occasions when it is necessary to use loose pieces on large patterns. However, in the main, this should be avoided when a core can be used between the point involved and the mold parting. Some reasons for this are:

a. A loose piece may shift in ramming, particularly if it becomes very loose on the pattern.

b. When the loose piece is removed, the mold may be damaged in a way that makes patching difficult, so that a good casting cannot be made.

c. The use of loose pieces slows up production and requires more skilled men. Therefore, deliveries are slowed up, costs increase, and neatness and accuracy of the castings are jeopardized.

d. Loose pieces should be plainly numbered, if they *must* be used. This applies to the core box as well as to

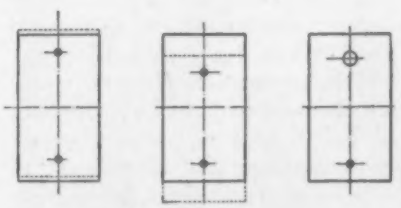


Fig. 3—Diagrammatic illustration of how carelessly placed dowel pins may cause molding errors and how the errors may be avoided. Left—Dowels placed almost symmetrically. Dotted line shows a part of the pattern shift that might not be noticed if the cope is reversed. Center—Dowels are definitely off center. If the cope pattern is reversed, the molder will notice it at once. Right—Two different sized dowels are used and it is impossible to reverse the cope part of the pattern.

pattern loose pieces. Faint marks, so often used to designate the location for loose pieces, soon disappear after a pattern or core box is used a while. It is then very difficult to tell where the parts belong. If there are many loose pieces with different combinations, there should be a log or index stamped on the pattern and core boxes showing the numbers of the

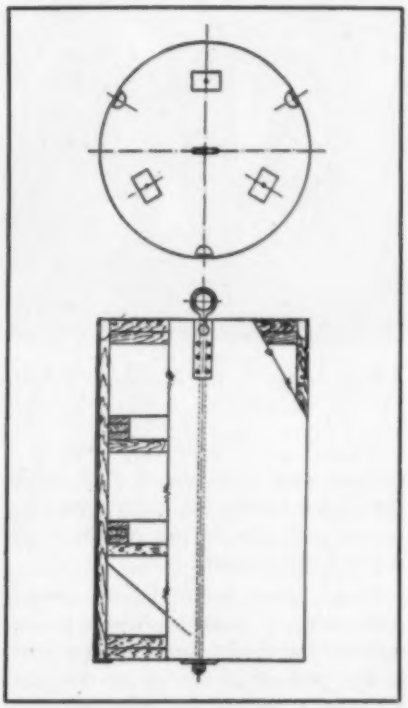


Fig. 4—Sketch showing (a) draw straps running down outside of drum pattern and hooking under the pattern, and (b) draw bolts running down inside of the drum pattern to plates on bottom. In either case, note strong bracing inside the pattern so that it will not distort or expand when the pull is applied to withdraw pattern from the mold.

loose pieces and the combinations required to make the proper casting. This is necessary so that the foundryman really knows when he has the right pieces in the proper location. It is a simple precaution to reduce the scrap castings and avoids delicate situations with customers resulting from errors which are costly, yet virtually unavoidable, if proper patterns are not provided.

Dowel Pins. The author wonders if patternmakers have ever thought of the scrap caused by putting the same sized dowel pins on each end of a pattern and then keeping the

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Fig. 5—Pattern for a heavy marine cylinder. It is made in sections, arrows indicating four outside sections. Center section not shown.

pins so near centerlines that, after the molder rolls the drag over, he cannot tell how to put on the cope part of the pattern.

Dowel pins should be off center sufficiently to make it obvious to the molder that he has put the cope part of the pattern on wrong, or the patternmaker should use two different sized dowel pins so that it is impossible to put the cope half of the pattern on wrong (Fig. 3).

Draw Straps. On large patterns, the matter of draw straps or draw bolts is important. The author prefers draw straps. If the pattern is large, such steel straps should extend down to the bottom of the pattern and hook under it, so that the pull will be from the bottom. The straps should be placed on the pattern core print, if that is practical. If they must be on the pattern, it is advisable to set the strap into the pattern to avoid excessive mold patching.

The pattern should be well braced and built around the point where the straps will pull. If this is not done, the pattern will be so badly twisted after one or two draws that it will have to be repaired before additional castings can be made. As stated, the author prefers draw straps on a pattern because he believes that their use is simpler and less likely to damage the pattern for future use. If well constructed, a pattern with draw bolts is a good pattern, provided its construction is planned so that the pull is directly from the bottom of the pattern (Fig. 4).

Sectional Large Patterns

It seems to the author that patternmakers seldom think about building a large pattern in sections around a center that can be drawn out separately from the outside sections. One wonders sometimes if those learning the trade have ever heard about the method. Let us describe a case in point. The job is a large marine cylinder which will weigh about 11 tons. It is to be cast on end.

If the pattern is made in one piece and provided with good draw straps, the pull is enormous when the pattern is removed from the sand; first, because of the friction of the sand against the pattern, and second, because of the vacuum created as the pattern starts to leave the bottom of the mold. This strain is hard on the best of patterns and, after being used a relatively few times, the pattern is ready for rebuilding, if accuracy is to be maintained—in fact, if any castings are to be made at all.

Suppose a center is made around which four sections are built (Fig. 5). Then, when the mold is rammed, the center part of the pattern is drawn easily and each section easily removed separately afterward, leaving the mold in good condition for economical finishing. With such construction, the pattern is not damaged. The foundry with which the author is associated has had a cylinder pattern of the type described in use for over three years without requiring any major repairs.

This clearly shows the advantages of such construction. This method of pattern construction often could be followed with profit on large patterns where more than one or two castings are required. It would preserve the pattern investment for the purchaser and give him better castings. Such patterns are easier to handle, and easier to store.

Pattern Distortion

Many times, the patternmakers seem to forget that lumber will swell when it remains in the mold for any length of time. This is due to dampness of the sand and is an important point to remember. Take for instance a long, flat pattern, such as a surface or bolster plate. The boards in the pattern should not be put on the face tight to each other. There should be a 1/16 to 1/8-in. spacing between them on the large surfaces to allow for swelling. This retains greater accuracy in the patterns and makes better castings.

Side Boards to Bottom. One of the nightmares of a foundryman is to get large patterns with the side boards not extending to the bottom of the pattern. The patternmaker will build up the sides like a box and then put on the bottom. He usually will finish the bottom edge to a good match before it leaves the shop (although many times he does not do a good job of that either).

Invariably, after such a pattern is in use, the bottom boards swell, and then they will extend a little over the side wall boards of the pattern. When that takes place, the pattern is securely anchored in the mold. All that can be done under such conditions is to pull and pull until the mold is destroyed in getting the pattern out, or until the pattern is broken drawing it out of the mold. One rule which should be followed in large pattern construction is "Always run the side boards of a large wood pattern to the bottom."

Pattern Draft. The author sometimes wonders how patternmakers expect a foundryman to hook out

pockets where there are deep ribs, when little or no taper or draft is allowed. Without sufficient draft, the pockets will be torn when drawing the pattern. This is especially true in lifting off the cope. The result is that much time is spent by the molder in patching and nailing. This requires excessive finishing, which results in increased costs and lower quality castings.

Core prints are another problem facing the foundrymen. Core prints are used to support and to help hold the core in place. It is difficult to make a rule, and a visit to the foundry by the patternmaker will help considerably. One gets better castings if he does not have to reduce the size of the core by rubbing.

Shrink Rule

The patternmaker makes the mistake of constructing the pattern and core to the same shrink rule for large patterns. For small bench work, made in green sand, the same rule can be used. But for larger castings, made in dry sand, it is a headache to the foundry. To help this condition *use the shrink rule on the pattern and the common rule or 1/16-in. shrink rule on the core box.* Then the core will readily go into and fit the core print without rubbing.

Taper on Core Prints. Core prints, in the bottom of a mold, should have a slight taper. Where the core is not tapered to suit the core print, the smallest part of the core print should be made to fit the straight part of the core, the taper providing the clearance.

Cope and Drag Prints. It is advisable to avoid putting core prints on the cope side of a pattern unless they are used to locate a core or to hold a core in place. Cores, that are secured in the drag and cut through to the cope, do not need cope core prints because the cores are already located in the mold and the touch of the cope holds them in place. Therefore, by omitting the core prints in the cope simpler molding is provided. Such practice also helps to make cleaner castings by eliminating the danger of crushing when closing the mold for the last time.

There are some cases where core prints should be omitted in the drag, if possible. For instance, where the body of the core is larger than the core print, it is impossible for the molder to see the core print when he sets the core. He works blindly.

Length of Core Prints. The length of core prints depends upon their position and their purpose in the mold. If they are to locate a core, they should be about 1-in. deep, but if they are to support a core and hold it in place, they may run from 1½ to 5 or 6-in. long, depending upon the weight and size of the core.

Short core prints often cause scrap castings because they will not support the weight of a heavy core running crosswise in the mold and do not provide sufficient bearing to hold a core correctly in position. Likewise, if core prints are too short and lie horizontally, venting to remove gas created in pouring is almost impossible.

Clearance on Core Prints. Patternmakers could provide simpler molding by allowing clearance in the drag half of the core print as well as in the cope half. This saves the molder from shaving back the core print or rubbing the core. In other words, a sand core has rods in it and, in drying, may have small heat cracks, making the core a little longer. The longer the core, the more rubbing a molder must do to get the core into the mold. The rubbing could be avoided by allowing the same clearance on the drag half core prints that is customary for the cope half core print.

Witness on Core Prints. Witnesses on core prints should always be included (1) when it is possible to reverse the core when placing it into the mold, (2) when the core can be used in either of two places and is correct in only one, or (3) rotation of the core will make an improper casting.

This thought seems simple and unnecessary. It would be out of place only for the fact that patternmakers so often neglect to put witnesses on core prints under these conditions, and in such cases the foundryman runs into trouble. Allied to this same thought is the matter of loose core prints on a pattern held in place by dowel pins. If the dowel pins are the same for several loose prints so that they can be reversed, trouble results. Ways should be used to prevent such errors, either by witnesses or other methods.

Fillets. To have a molder cut fillets on a mold where the patternmaker indicates that they should be, by mark with a crayon or color paint, makes expensive molding, because the mold has to be cleaned out after the fillets are cut and that takes time. It also might be added that, when fillets are so cut, they are not always a good job.

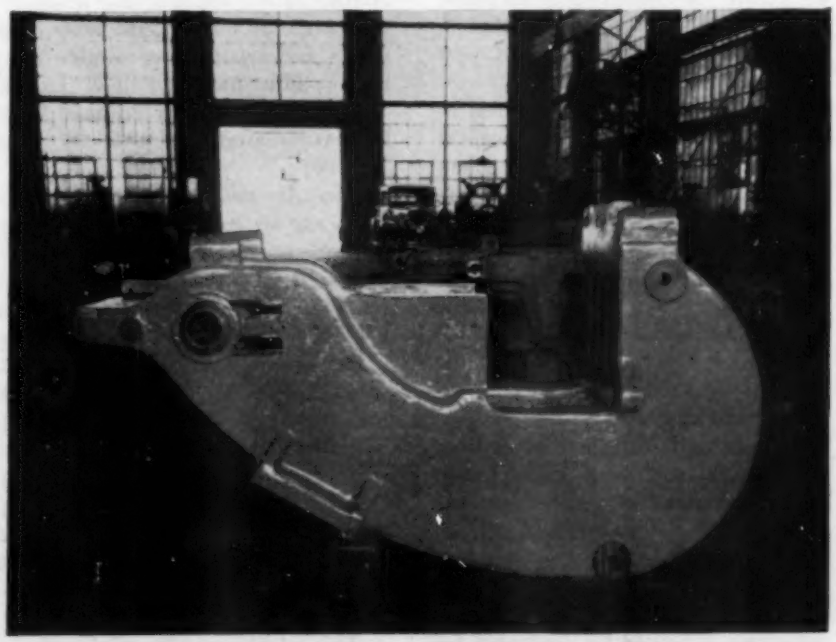

Fig. 6—Frame for a punch press. The broken casting was used as a pattern. The frame was split. The center was lifted out with an arbor. Lagging was put on to allow for shrinkage and finish where required. The mold was ready 3 days after the broken casting arrived at the foundry.

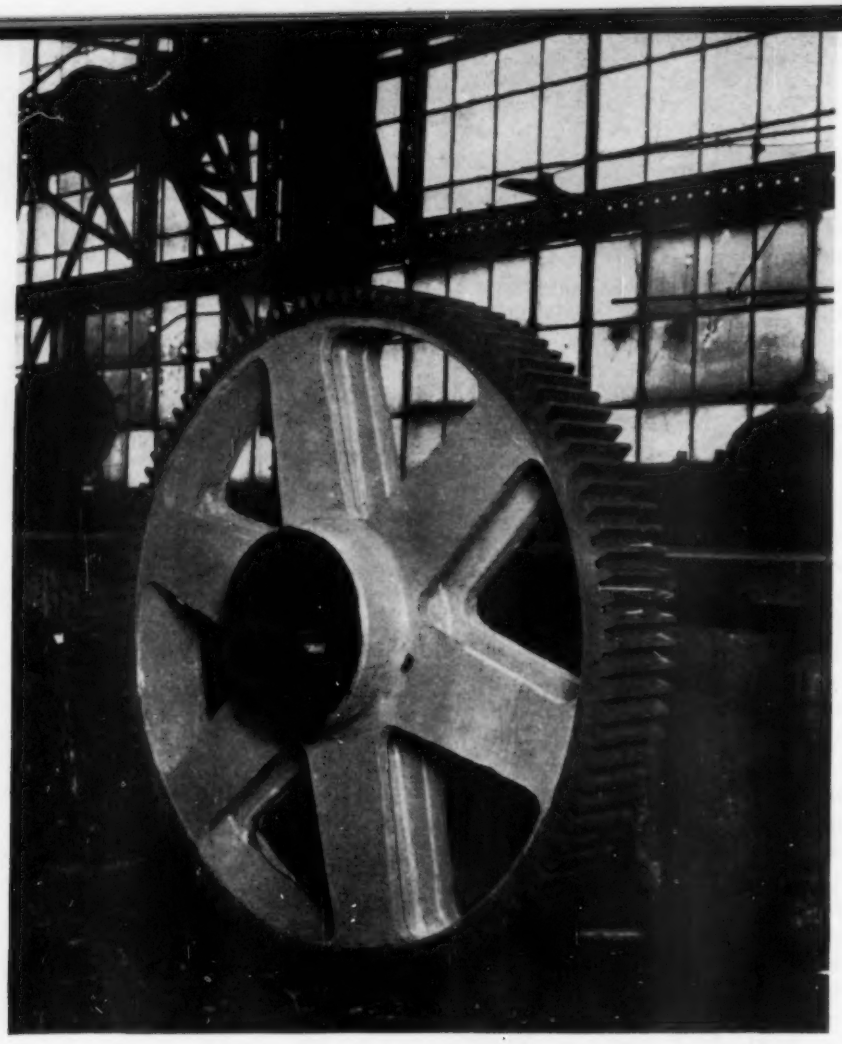

Fig. 7—Large bull gear. Only one was required. To make the casting, all that was required was (1) a sweep to form the bottom of the mold, (2) a pattern section for ramming the outside, and (3) core boxes to set up one section from arm to arm.

Therefore, it should be concluded that for better casting appearance, the fillets should be mounted permanently on the pattern.

This subject might be referred to as patterns for one casting or, at the best, two or three. This problem needs consideration because, if the pattern for such a part is made to standard practice, the cost is so great that the finished part is very expensive. Because of this high cost, the buyer may consider other ways to solve his problem at a lower final cost and may begin to figure the use of weldments instead of castings. Such a procedure by the buyer loses business both for the pattern shop and for the foundry. Often there are ways to reduce this over-all cost by better pattern and casting planning.

If the patternmaker would seek the foundryman's assistance on such occasions, it would be profitable for both the foundry and pattern shop.

Using Castings for Patterns. Old castings often can be used as a body for a pattern by lagging certain parts of the casting for machine finish or shrinkage, by building on some core prints and by making suitable core boxes. This makes a low pattern cost, a slightly higher casting price, but a reasonable over-all cost (Fig. 6).

Core Assembly. Take a large gear blank as an example of a casting, only one of which is to be made. The expense for a full pattern is too great to make an over-all cost practical. On the other hand, one can make a segment pattern to form the outside diameter of the mold and work it around a spindle after sweeping a flat bottom. Then he can make a segment core box for half cores, working off a proper parting line. And finally, one can use a flat cope rammed on a plate; or cover cores, weighed off to secure the main cores forming the arms and hub.

This planning will give inexpensive pattern rigging for one large gear blank at a reasonable over-all cost that will be practical under the conditions. The segment patterns and core boxes are not too expensive. The casting cost itself may be a little over normal, but the over-all cost is consistent for such a job.

Figure 7 shows how sweeps and core assemblies can be used as an economical procedure to meet competition under these circumstances. It is an old practice that is being forgotten by the younger patternmakers.

Pull-up Patterns. Let us consider pull-up patterns or sweeps as another short cut for these one-time or short-run jobs. The type of castings, where this practice applies on small orders, is for castings like a pipe, cylinder liner, or crane drum. Suppose the job is to be 6, 8, or 10 ft. long. It can be cast on end. Here it is possible to use a section of pattern only 24 or 30 in. long.

The molder can keep drawing it up to a gage stick as layers of the mold are rammed, until the correct height of ramming has been obtained. Again, such a pattern is relatively inexpensive and, while the casting price may be a trifle more than normal, still the over-all cost of the job to the customer is reasonable. The pattern storage problem also is simplified. In fact, the pattern may even be thrown away.

This pull-up procedure applies mostly to jobs which are big enough to allow the molder to either get inside or reach inside for finishing the mold. However, sometimes a mold can be split into sections so that the molder can finish the mold by reaching, when the sections are separated.

Sweep Patterns. Another and cheaper way for making these larger cylindrical-type jobs should be mentioned. That is by using sweeps for loam molding. Here again, pattern costs fade away. The mold cost increases somewhat, but a nice job is obtained at a reasonable over-all price to the customer.

Half Patterns. Many jobs are symmetrical and many foundries are tooled to take advantage of this symmetry by using only half patterns. Such practice reduces pattern costs against the job. In fact, even on good production jobs, half patterns can be used if one knows that the foundry works off molding plates or molding boards using good pin centers.

The pattern can be properly and

accurately mounted around center lines to produce excellent castings. In such cases, a full pattern is a waste of money. The author believes that, as a matter of good will between customer and pattern shop, and foundry, these economies always should be employed.

Carrying this thought further, the author often has used quite large half patterns without mounting them on a plate or board. Suppose a job is to be made on its side. A half pattern is made, and then a dummy is made to fit into the core prints of the drag half of the mold and strips are run along the joint of the drag to support the half pattern when it is used for the cope. Methods like those which have been mentioned should be remembered for these one-time requirements to keep the customer casting-conscious and satisfied.

Skeleton Patterns. Let us consider skeleton patterns. They may be considered to be in two classes: (1) *plain*—for flat or bolster plates, etc., and (2) *larger*—for rather complicated castings.

The foundry has a customer who purchases many die plates for metal-working dies. To keep the costs reasonable, the patternmaker made a frame of the right thickness on which he placed bosses and cross supports where he wanted them. These were put on tightly or with dowels. He made sweep sticks to strike out the metal thickness within the frame before drawing the pattern from the drag. This was a simple, inexpensive pattern procedure. No pattern was used more than once.

The customer used so many patterns that storage was impossible. The result was that we charged a little more for castings than we would have charged with first class patterns, but the over-all job costs were much lower. We sold this customer thousands of dollars worth of castings each month. It was a practical solution to the customer's problem.

This instance shows again how the patternmaker, foundry, and customer can cooperate to the advantage of all from a good business standpoint. It is one way for foundries to meet competition on this kind of work.

The other field for skeleton patterns is for large pipes, cylinders, valve bodies, etc. In this case, the pattern shop also must work with the foundry. Sometimes the core can even be rammed in the mold. In either case, after ramming, the metal thickness is cut out by sweeps.

As an illustration of how this works, it might be mentioned that the author's foundry made a series of pumps and valve body parts for a firm in California some years ago. The castings weighed from 4 to 8 tons each. Figure 8 (see front cover) shows the large pump housings made from skeleton patterns which were destroyed after the job was finished. The skeleton was so made that the core was made in the mold and lifted out with an arbor for finishing and drying.

The pattern shop cooperated in making skeleton patterns, which brought the pattern price sufficiently low to make an over-all job price practical. As a result, the customer placed the order in Cleveland instead of shipping the castings from the West Coast where better patterns existed. When the job was finished the patterns were scrapped.

This represents an ultimate in design of patterns for short-run requirements. It is a practice, however, that must be given more attention and one that patternmakers should be thinking about for future competition.

Shellac and Color

The author believes that almost every foundryman feels that if a wood pattern is made and good shellac, or some substitute for shellac to which sand will not stick, is not available, then *leave the shellac off the pattern altogether.*

It is certainly disheartening to the molder and disastrous to costs, as well as destructive to quality, to draw a pattern and then find a large amount of the molding sand stuck right to the pattern because of poor shellac. Poor shellac can make a mess of a mold. Therefore, do not try to save a few pennies on shellac.

As for color, it is so long ago since the American Foundrymen's Association started advocating red for finish surfaces, yellow for core prints, and black for the unfinished parts of the casting, that those who participated in drawing up the A.F.A. Standard Pattern Colors are beginning to feel like old men. Yet, the practice of using these three colors properly is followed very little. The writer is sure that foundrymen would recommend that patternmakers follow this procedure. It would be helpful.

Shrinkage is no real problem on small patterns, but horse sense must be used about shrinkage on large patterns. The author will point out a few of the larger hazards.

Iron or steel will shrink a certain amount per foot of length when cast in a straight bar. But, that is not definite assurance that complicated castings, having many cores, or that castings of various shapes will shrink that same amount per foot in all directions. They do not. That is the reason why good, practical judgment must be used in laying out a pattern from a shrinkage standpoint.

Shrinkage

Take a long bed plate, a long pipe, or a cylinder with flanges on the ends. Who knows absolutely that it will shrink, say one-tenth in. per ft. on the length between flanges? One cannot be sure. The cores probably will hold the casting and not allow it to shrink fully. If the casting is not allowed to shrink fully, how about the end flange thickness after machining? They will be thin and perhaps the customer will not take the job.

To obviate this, the flanges should be backed-up with extra metal. Make the flanges sufficiently heavy so that they will not be too thin if the casting does not shrink as planned. The outside ends will certainly have plenty of finish, but look out for the inside dimensions. Allow extra finish or back-up the flanges, or do both.

If pattern dimensions are checked against dimensions of castings made from those patterns, it will be found that the shrinkage problem is an uncertain one and that it is necessary to safeguard pattern dimensions by allowing for probable variations.

As an example, let us consider cylindrical castings with cores. Such castings do not shrink "to rule" on the diameter. Most of the shrinkage is lengthwise. Often it is necessary to make larger cylinders with shrinkage allowance slightly over common rule measurements on diameters. If such allowance is not made, when the job is finished there is too much finish on the outside diameter and none or practically none on the inside diameter.

To illustrate this point, some time ago the foundry took on a liner job

in which the liners were made with finish bands only on the outside diameter, to save machining cost. The customer was objecting because he had to machine the whole length of the outside diameter to use the casting. There was practically no finish on the inside. We measured the pattern and the casting on diameter. They were alike. No shrinkage had taken place on diameter; it was all lengthwise.

Thereafter, on this type of job, the customer used common rule on the diameter and shrink rule on the length when making this type of pattern. This is only one illustration. Many such instances could be quoted on piston rings, wire blocks, and other circular parts, to show that precautions must be taken for a sensible use of shrinkage allowances, as derived from experience and casting design.

Smaller items to be watched in making jobbing patterns are placing core prints properly to get core balance in a mold, and placing them so that core wires and core rods can be removed from the casting. One also might mention some generalities about plain practicability of patterns for molding, such as the avoidance of three-part molding, etc.

Figures 9 and 10 illustrate patterns in which moldability has not been considered. On the left in Fig. 9 is a pattern as supplied by a customer and which required three-part molding. The molding cost was high and good castings were difficult to make.

At the right in Fig. 9 is the new pattern for the same casting. This pattern required only cope and drag and a core was used to form the center portion. With the new pattern, molding was easy, cost reduced and more accurate and better appearing castings produced.

Figure 10 shows a pattern that is improperly designed. It is a bench job. The flange, as can be noted, was made as loose sections which are held in position with pins. Molding was extremely slow and only the most skilled molders could be used. The castings made from this pattern were not of high quality.

This pattern should have been made as a split pattern, which could have been molded on the side using a flat parting. Had the pattern been so made, costs would have been reduced materially and better castings produced.

Many problems, incident to the use of miscellaneous patterns in a jobbing foundry, have been mentioned, and a short summary of the main points might be helpful.

1. Split patterns are the most desirable type for many reasons, among them lower costs and better castings. Seldom is a solid pattern preferable, when straight parting is impossible.

2. The problem of loose pieces on patterns and in core boxes needs constant attention for good operation.

3. Care in the use and placement of dowel pins will prevent many errors and reduce casting losses.

4. Large patterns, properly reinforced and provided with proper draw straps, thoughtfully placed and securely fastened, will contribute to better castings at a lower cost and to longer pattern life.

5. When designing large patterns, consider sectional pattern principle.

6. Applying the lumber to patterns properly will help jobbing foundries and give customers better castings and pattern satisfaction.

7. Make core prints properly so that the cores may be correctly located, locked and secured. This is an essential point in better casting production.

8. Use good fillets to improve casting appearance and make sounder castings.

9. When designing patterns for one-time usage or for several castings, consider use of assemblies of cores, an old casting for a pattern, and skeleton patterns.

10. The proper engineering finish of a pattern with good shellac and standard colors is advocated.

11. Both patternmakers and foundrymen should become more familiar with shrinkage changes to give maximum satisfaction to the customer.

The author has shown that there is a close tie between patternmakers and the foundry, and that there should be close cooperation between them because they have a common interest. The foundry and patternmakers will prosper together and the customer ultimately will decide their fate. Today, sand castings have competition as never before from stampings, die castings, permanent mold castings, plastics, weldments, etc. We must, therefore, understand each other's problems and work together for the common benefit, which finally resolves itself into a cooperative effort to please the customer. The author hopes that this paper has been helpful in laying a better foundation for such benefits.

Fig. 9—(Above) Pattern required 3-part molding. (Center) New Pattern requiring only cope and drag.

Fig. 10—Improperly designed pattern. Flange is made in loose sections held in position with pins.

HIGH TEMPERATURE SAND TESTING

Fifth Annual Progress Report

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A BRIEF DESCRIPTION is given of a newly constructed furnace for elevated temperature research on the hot compressive and hot transverse strength of foundry sand test specimens.

Green hot compressive strength-specimen exposure time data for eight sand mixtures (mixture additions, western and southern bentonites, fire clay, cereal and silica flours) having 5 per cent moisture is shown for temperature control settings of 1600°, 2000° and 2500° F. This required the testing of 1119 specimens.

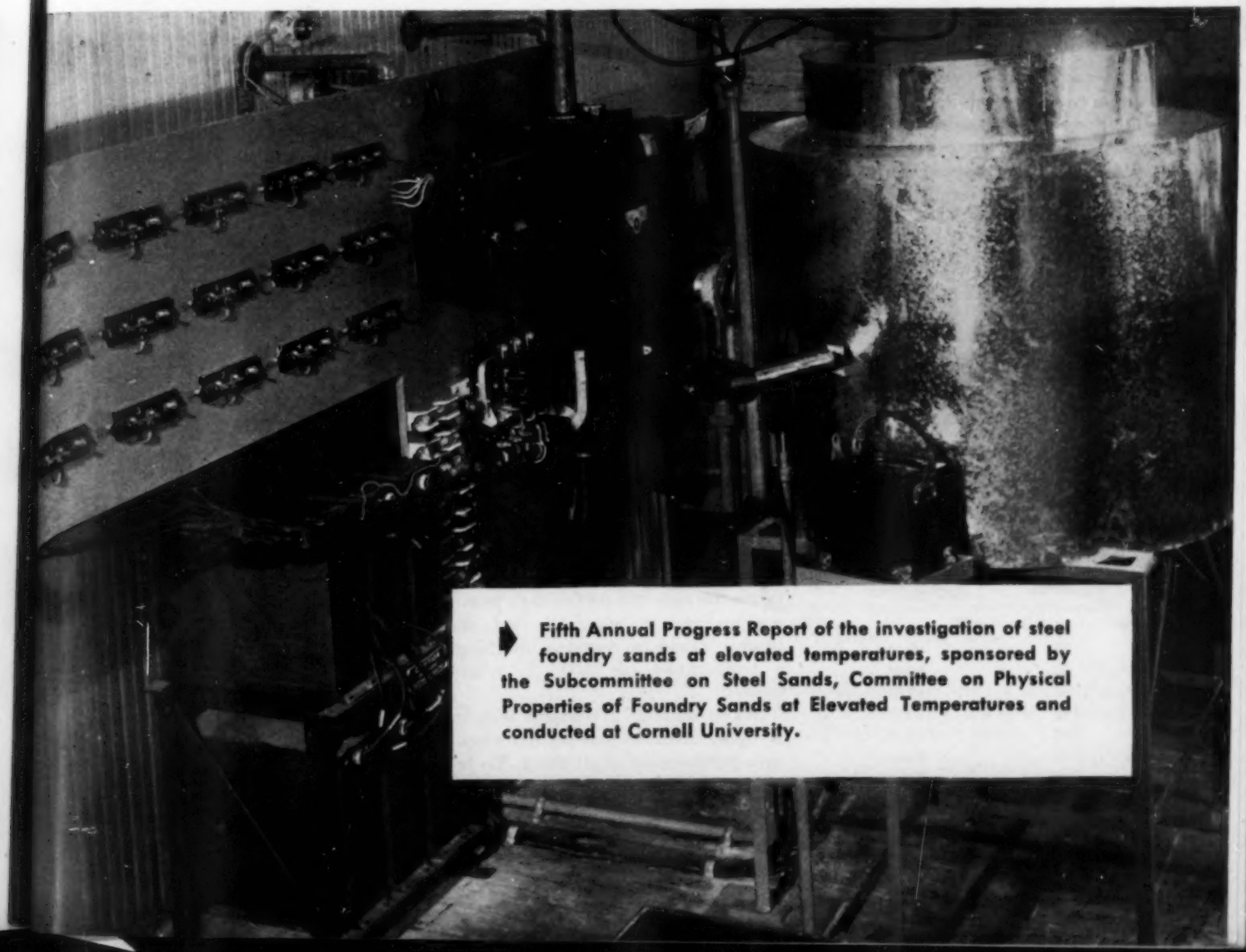
The addition of silica flour to the two kinds of bentonite mixtures increased the maximum and minimum hot compressive strength of the test specimen, whereas the addition of cereal flour did not appreciably affect these strengths at most of the temperature control settings (tendency toward lower strengths.)

The maximum hot compressive strengths for all test specimens occurred at temperature control settings of (1) 1600° F. for the bentonite mixtures and (2) 2000° F. for the fire clay mixtures. The minimum strengths for all mixtures occurred at 2500° F. and were substantially zero psi.

Little difference was found in the minimum hot compressive strength of the test specimen for fire clay and southern bentonite mixtures alone and when cereal flour was added.

Stress-strain data indicate it is desirable to load the test specimen at a constant strain rate. The maxi-

Fig. 1—New elevated temperature research furnace at Cornell University.



Fifth Annual Progress Report of the investigation of steel foundry sands at elevated temperatures, sponsored by the Subcommittee on Steel Sands, Committee on Physical Properties of Foundry Sands at Elevated Temperatures and conducted at Cornell University.

Table 1

SAND MIXTURES TESTED

	Composition, per cent						
Mixture No.	*Sand*	*Western Bentonite*	*Southern Bentonite*	*Fire Clay*	*Cereal Flour*	*Silica Flour*	*Moisture*
1	96	4	....	....	....	....	5.4
2	86	4	....	....	....	10	5.0
3	95	4	....	....	1	....	5.2
4	96	....	4	....	....	....	5.2
5	86	....	4	....	....	10	5.2
6	95	....	4	....	1	....	5.2
7	96	....	....	4	....	....	5.2
8	95	....	....	4	1	....	4.8
9	93	....	....	7	....	....	5.0

mum strain value for the western bentonite mixture was approximately twice the maximum value when silica and cereal flours were added to the bentonite mixtures.

During 1944, a change in the committee set-up for elevated temperature investigations took place. The work being done at Cornell University now is sponsored by the Subcommittee on Steel Sands, Committee on Physical Properties of Foundry Sands at Elevated Temperatures. During 1944, this work covered two phases: (1) the building of a piece of elevated-temperature testing equipment for research, and (2) the initiation of the foundry mixes program. H. W. Dietert presented a 1944 model of his dilatometer to the A.F.A. and it was installed at Cornell University to be used primarily in conducting the foundry mixes program. Werner Finster, chairman of the subcommittee, before the change in organization, wrote the following to the subcommittee regarding the new dilatometer and the foundry mixes program: "It was the thought of the officers of the subcommittee that the second dilatometer would be used as furnished by H. W. Dietert, and that sand mixtures, changing only one variable at a time, would be tested on this dilatometer. While it must be understood that data developed in this manner will only represent information as developed on this particular instrument, results of this investigation should be of help to the industry, which also is using commercial dilatometers."

Table 2

SCREEN ANALYSIS OF BASE SAND

U. S. Bureau Standards Sieve. No.	*Per Cent Retained*
40	0.51
50	10.15
70	40.95
100	35.40
140	10.90
200	1.92
270	Trace
Pan	Trace
	99.83

New Research Furnace

Four needed requirements for a research instrument to investigate foundry sands at elevated temperatures are: (1) means of observing the test specimen at all times during exposure to heat, (2) furnace heat capacity great enough so that the introduction of the test specimen into the furnace would cause a negligible temperature drop, (3) an air-free hydraulic pressure-loading system and (4) a piece of testing equipment with sufficient capacity to also conduct a transverse test at elevated temperatures.

In an attempt to satisfy the above requirements, B. A. Bovee, Carborundum Co., Niagara Falls, N. Y., designed a silicon carbide resistor furnace. The new furnace, Fig. 1, was built at Cornell University. The pressure-loading equipment is not shown because of difficulties in obtaining the necessary parts. At the present writing, the furnace has been taken through the preliminary heating up and it appeared that no trouble would be found in reaching a temperature of 3100° F. when desired.

When making a strength test, it is highly desirable that the test specimen be observed at all times. To be able to see just how cracks form may be valuable information. For research purposes, it is necessary to eliminate a furnace temperature drop if possible. The new research furnace has at least nine times the heat capacity of the commercial dilatometer furnace.

On the new research furnace the rate of table rise will be variable. A change in rate can be obtained by opening or closing a by-pass valve to the reservoir. It will be necessary to make the new hydraulic system air free.

When using silicon carbide heating elements, it is highly desirable that the electrical energy input be continuous. The electrical energy required to just about maintain a temperature control setting will be regulated manually. An additional small amount of the electrical energy input will be regulated automatically to maintain a temperature control setting. Capacitors (ordinarily used for power factor control) are used to regulate the energy input.

The specimen will be introduced into the furnace by means of a refractory skid. This skid is so arranged that it will be possible to alternate between a compression and a transverse test, as desired, without a time delay. The maximum size of the specimen that can be handled will be 2½-in. diameter or 2½-in. on one side and 6 in. long.

Foundry Mixes Program

The hot compressive strength results reported in the following are the beginning of this program. Succeeding progress reports will contain continuations of these studies.

The results for sand mixtures given in Table 1 were obtained under the following conditions:

(1) A 1944 model commercial dilatometer was used for all tests.

(2) A controlling thermocouple

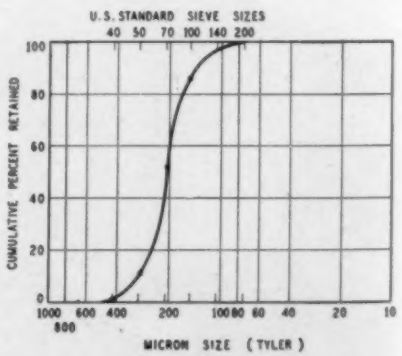


Fig. 2—Cumulative distribution curve for sand used for foundry mixes program.

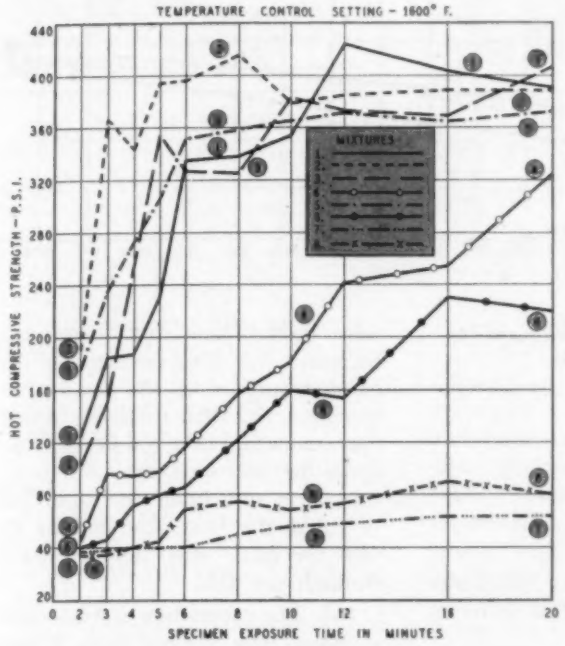


Fig. 3—Relation between hot compressive strength and exposure time on mixtures shown in Table 1, tested at 1600° F.

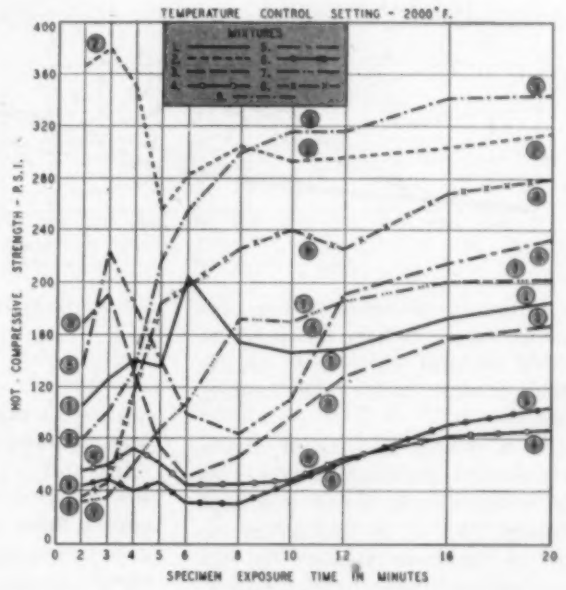


Fig. 4—Relation between hot compressive strength and exposure time on mixtures shown in Table 1, tested at 2000° F.

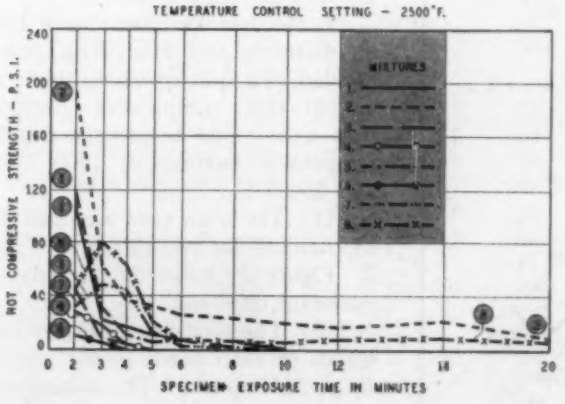


Fig. 5—Relation between hot compressive strength and exposure time on mixtures shown in Table 1, tested at 2500° F.

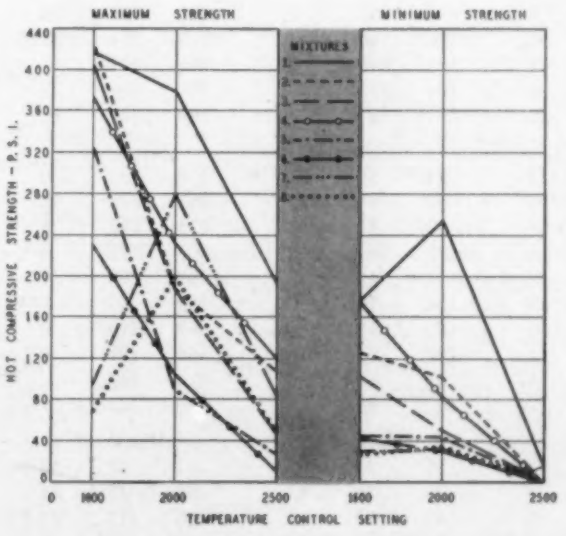


Fig. 6—Relationship between furnace temperature and maximum and minimum strengths obtained at different exposure times.

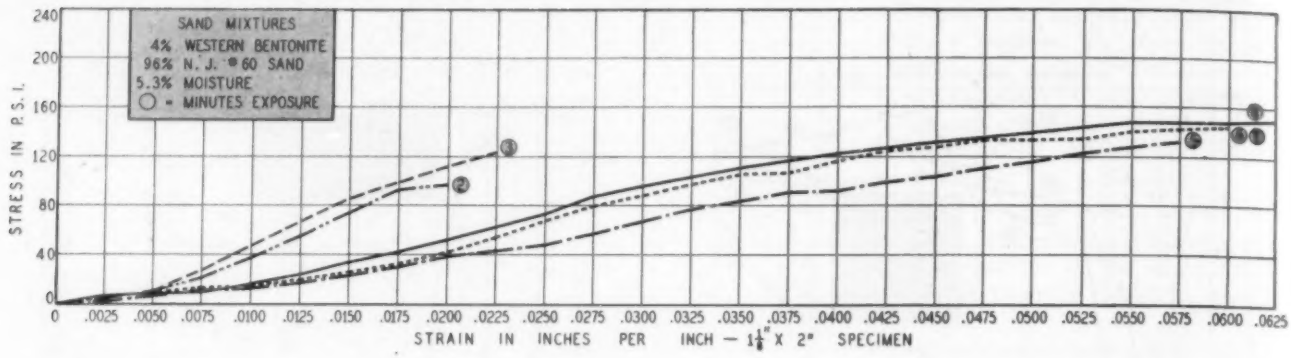


Fig. 7—Stress-strain diagram for Mixture 1, Table 1.

(platinum vs. platinum-10 per cent rhodium) had its bare hot junction located opposite the center of the specimen and inside the heating chamber.

(3) A double bore fused quartz thermocouple protecting shield. This type of protecting shield was used because: (a) it is transparent to most of the radiant heat; (b) for any chosen recovery time, the overheating of the element temperature was reduced approximately one-third, and (c) less impressed voltage was required to obtain a chosen recovery time.

(4) Refractory disks (mullfrax "S") 1-in. thick and 1⅜-in. diameter were used. These disks were used because: (a) they covered the expanded surface of the heated test specimen, (b) their thickness insured the conducting of a compression test upon the test specimen, and not a transverse test upon the disk, and (c) that the heat absorbed by the test specimen was not dissipated through the disk.

(5) The controlling thermocouple recovery time ranged from 2 min. 15 sec. to 2 min. 45 sec.

(6) The pump motor was started so that contact between the upper post and top disk was made within plus or minus 2 sec. of a given exposure time (contact indicated by a rise in gage pressure).

(7) Trapped air in the hydraulic pressure system could not be removed; evidence of trapped air was indicated by a sudden plunger jump when the test specimen ruptured.

(8) All tests were made using green sand specimens.

(9) All test specimens were 1⅛-in. diameter and 2 in. long, being molded in a split specimen tube.

(10) Hot compressive strength tests were made at furnace control temperature settings of 1600, 2000 and 2500° F.

(11) The silica sand used had the mechanical analysis shown in Table 2. Figure 2 shows the cumulative curve for this sand.

(12) The total weight of dry materials or each batch mixed was 10 lb. or 4500 grams. The mixing was carried out in a 24-in. laboratory mixer (revolving muller type) and the batches were mixed 2 min. dry and 5 min. after the distilled water was added. The hot compressive strength testing was started immediately after mixing.

(13) The mixtures tested are shown in Table 1. The numbers of the mixtures correspond to the numbers of the curves, showing the rela-

Table 3

VARIATIONS IN HOT STRENGTH (PSI.) OF VARIOUS SAND MIXTURES WITH EXPOSURE TIME (AVERAGE OF FIVE TESTS) (EXPOSURE TEMPERATURE, °F.)

Exposure Time, Min.	*Mixture 1*			*Mixture 2*			*Mixture 3*		
	1600	*2000*	*2500*	*1600*	*2000*	*2500*	*1600*	*2000*	*2500*
2	127	104	108	176	365	194	101	165	46
3	186	126	21	369	380	62	152	190	7
4	188	140	17	346	352	35	253	136	4*
5	234	134	10	395	252	32	357	73	0
6	336	206	7*	397	283	26	327	50	0
8	339	153	6	415	306	24	325	66	....
10	356	146	2	379	294	20**	382	98	....
12	425	148	0	386	297	17	374	128	0
16	404	173	....	391	304	22	370	158	....
20	391	183	0	389	316	10	396	168	....
	Mixture 4			*Mixture 5*			*Mixture 6*		
2	44	53	27	176	135	120	41	42	11
3	97	59	19	235	225	32	46	50	7
4	95	72	4	275	182	8	73	40	0
5	99	61	0	305	142	6	81	50	....
6	118	43	0	352	98	7	88	32	0
8	148	44	0	359	84	2**	123	34	0
10	185	48	....	367	110	0	161	45	....
12	244	64	0	366	191	0	156	65	0
16	256	82	....	374	216	....	232	92	....
20	326	84	....	373	232	....	222	106	....
	Mixture 7			*Mixture 8*			*Mixture 9*		
2	36	31	29	37	33	42	78		
3	36	34	47	38	45	81	99		
4	40	59	45	40	113	61	142		
5	40	87	12	49	183	20	218		
6	41	108	4	71	197	9	256		
8	51	172	0	76	227	4	299		
10	57	170	0	70	241	5	316		
12	58	177	....	76	226	7	320		
16	64	202	....	92	270	8*	343		
20	64	204	....	84	280	4**	345		

* Four tests.
** Three tests.

tionship between exposure time and hot compressive strength.

(14) The moisture content of the mixtures tested varied from 5.0 to 5.4 per cent, with one exception of 4.8 per cent.

(15) Each point plotted represents an average of five tests except when the strength was zero and three tests were made. Average test results are shown in Table 3. A total of 1119 tests were made in order to plot the curves of Figs. 3, 4, and 5.

Figure 6 shows the relationship between the furnace temperature control setting and the maximum and minimum strengths obtained during exposure periods of 2 to 20 min. The following points may be noted:

(1) The maximum strength for all bentonite mixtures tested occurred at a temperature control setting of 1600° F.

(2) The maximum strength for all fire clay mixes tested occurred at a 2000° F. temperature control setting.

(3) With the exception of mixture No. 2 the minimum strength curves show decreasing strength as the temperature control setting is raised from 1600 to 2000 to 2500° F.

(4) The addition of 10 per cent silica flour to a 4 per cent western bentonite mixture did not increase the maximum hot compressive strength at a temperature control setting of 1600° F. At temperature control settings of 2000° and 2500° F. the silica flour addition approximately doubled the maximum strength.

(5) The addition of 10 per cent silica flour to a 4 per cent southern bentonite mixture increased the maximum and minimum hot compressive strength at all temperature control settings.

(6) The addition of 1 per cent cereal flour to 4 per cent western and southern bentonite mixes generally indicated some change in the maximum hot compressive strength. In some instances the reduction or increase in strength is slight.

(7) The addition of 1 per cent cereal flour to a 4 per cent fire clay mixture increased the maximum hot compressive strength at all temperature control settings. No change was noted in the minimum hot compressive strength at any temperature control setting.

(8) As a temperature control setting of 2500° F., all the mixtures tested had very little or zero minimum hot compressive strength.

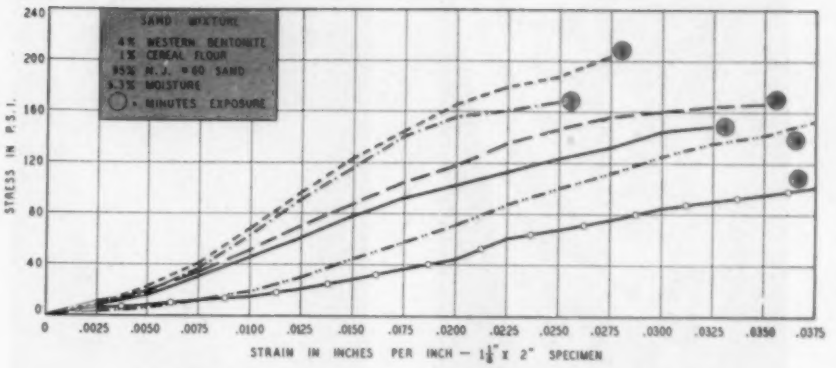

SAND MIXTURE
4% WESTERN BENTONITE
1% CEREAL FLOUR
95% N. J. #60 SAND
5.3% MOISTURE
○ = MINUTES EXPOSURE
STRESS IN P.S.I.
STRAIN IN INCHES PER INCH — 1½" X 2" SPECIMEN

Fig. 9—Stress-strain diagram for Mixture 3, Table 1.

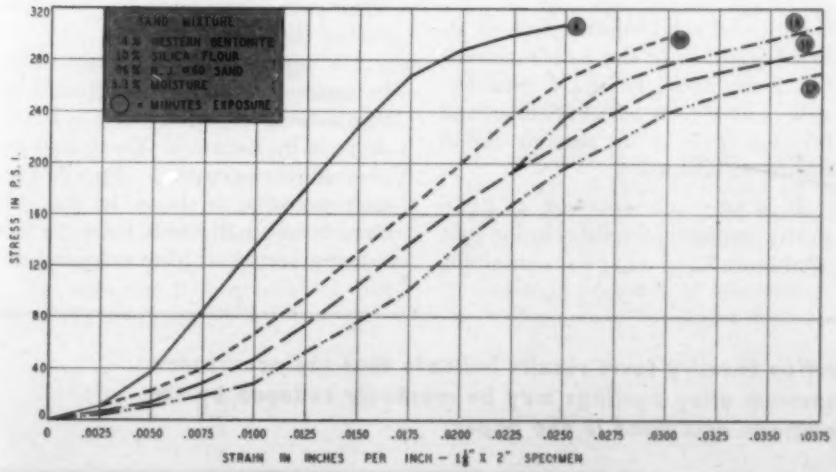

SAND MIXTURE
4% WESTERN BENTONITE
10% SILICA FLOUR
86% N. J. #60 SAND
5.1% MOISTURE
○ = MINUTES EXPOSURE
STRESS IN P.S.I.
STRAIN IN INCHES PER INCH — 1½" X 2" SPECIMEN

Fig. 8—Stress-strain diagram for Mixture 2, Table 1.

Stress-Strain Curves

Stress-strain data for mixtures 1, 2 and 3 (sands bonded with combinations of western bentonite, cereal and silica flours) will be found plotted in Figs. 7, 8 and 9. Each point shown represents an average of three to five determinations, and all tests were made at a temperature control setting of 2000° F. The strain values were obtained from the rise of the dirt pan and the values of strain were recorded just prior to the indication of stress in order to determine zero strain.

The initial slope of the curves indicates that at low values of stress there is a compacting of the test specimen.

The shape of the curves indicates that it is desirable to load the test specimen at a constant strain rate.

The final strain value for mixture No. 1 was almost twice the final strain value for the other two mixtures, indicating that the former was definitely more plastic.

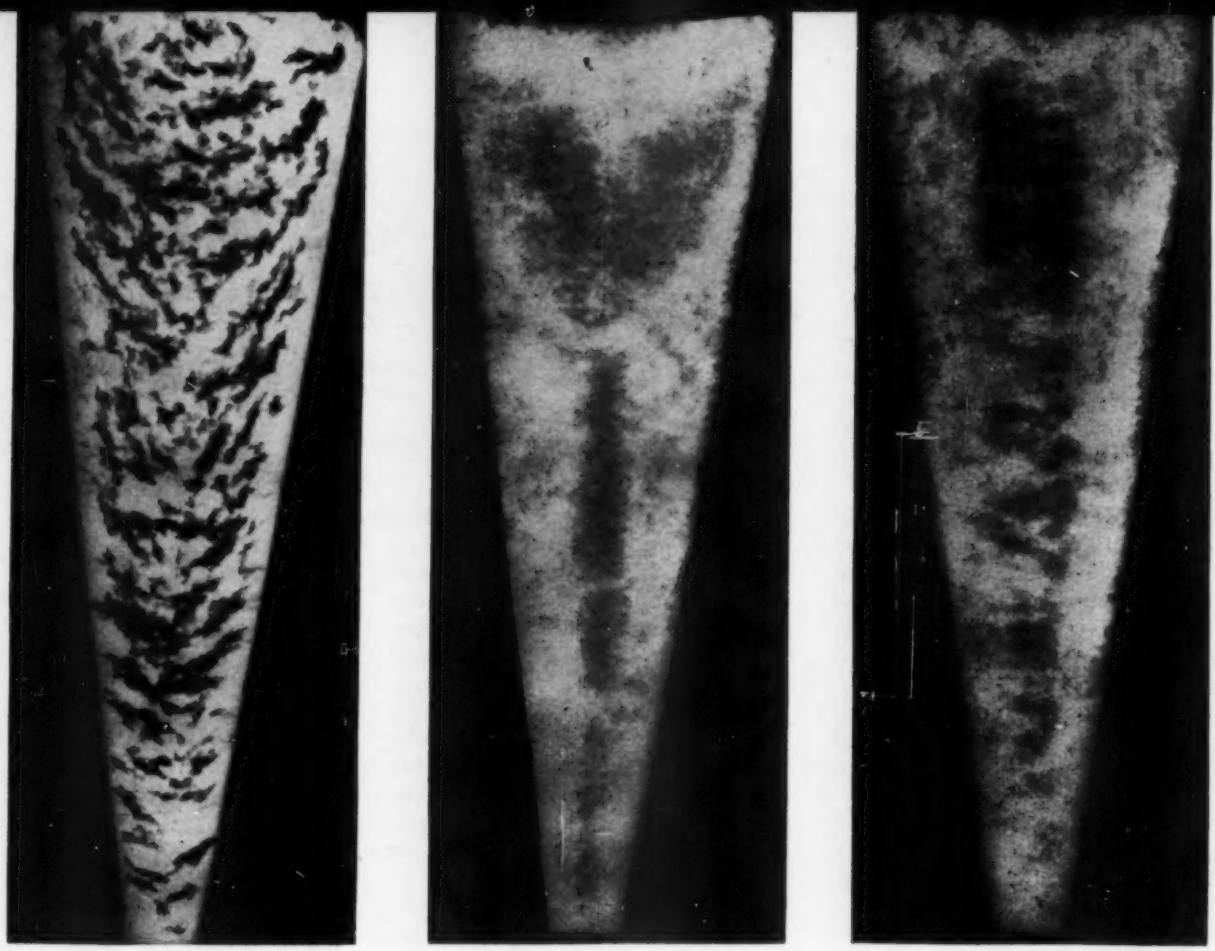
A study of the distribution of test data has been started and probably will be completed in time for the next annual report.

Acknowledgments

The writer wishes to express appreciation to Professor J. R. Moynihan for his advice and encouragement; to Dr. H. Ries for his continual interest and support. Also, the writer appreciates the assistance of Miss Saville Maney and Mrs. M. T. Richards in obtaining the stress-strain data. The writer wishes to thank A. W. Jenkins, D. Bacon, S. W. Cross, B. P. Fisher and S. Patch for their advice and assistance in constructing the new research furnace.

The writer wishes to thank the Carborundum Co., Globar Div., for supplying the heating elements, and the Cornell-Dubilier Corp., for supplying the capacitors for the furnace.

The sand used for the foundry mixes program was supplied by the New Jersey Silica Sand Co.



Specimen No.	87B	98B	124A
Height of sound Metal, inches	1/8	1/8	1/2

Reduction of Microporosity in Magnesium Alloy Castings

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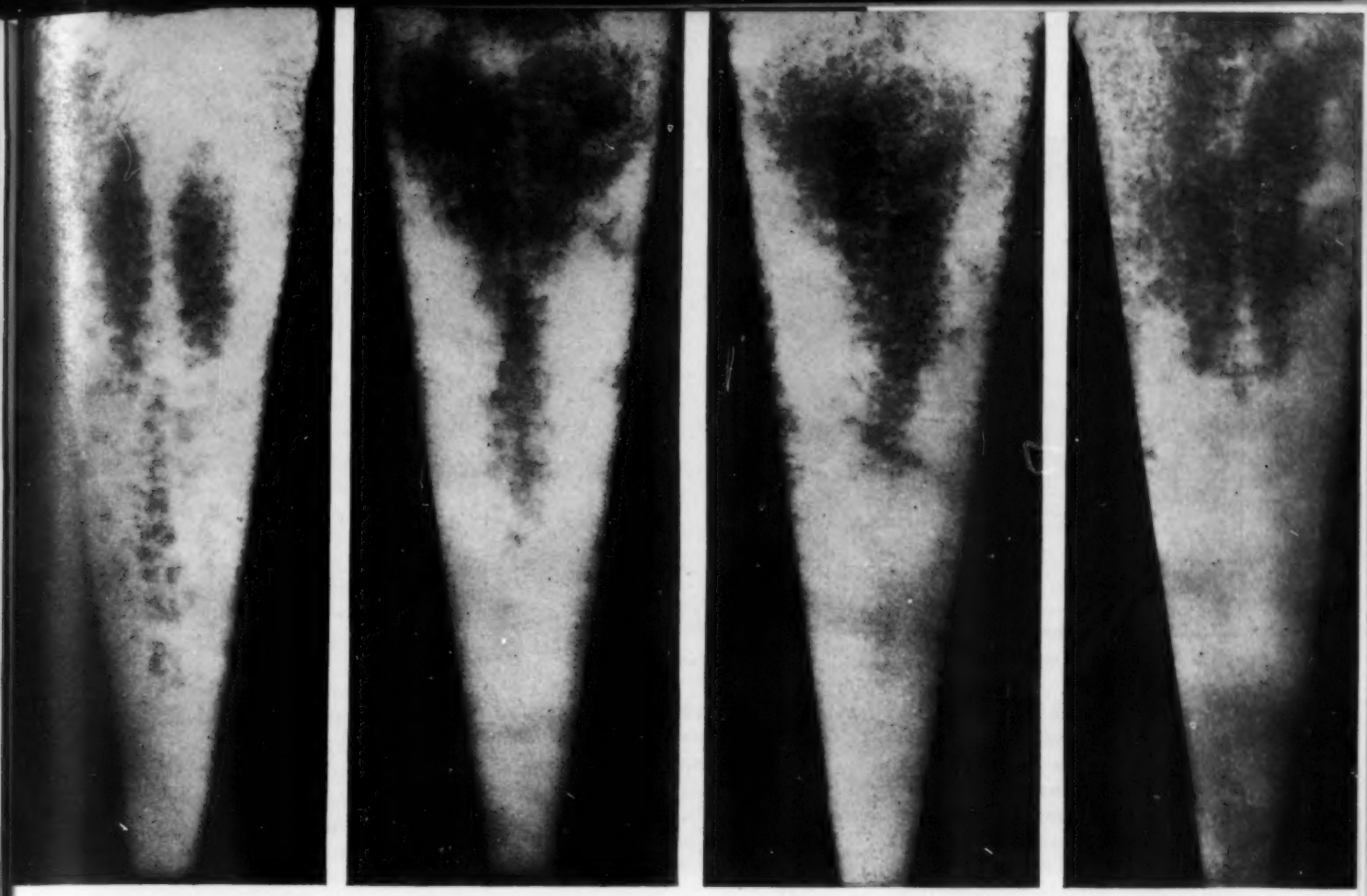
FROM the viewpoint of soundness of magnesium alloy castings, both the user and the producer are concerned primarily with the defect known as microporosity. Among light-alloy foundrymen, this term is used more or less interchangeably with "microshrinkage." The latter term is more specific, for it implies that the defect is caused entirely by shrinkage. For reasons which will become obvious, the term "microporosity" will be used in this paper.

Microporosity is by no means a malady characteristic of magnesium-base alloys only. It is common in commercial solid-solution type of alloys regardless of the base material; i.e., those alloys having a considerable range of solidification and forming little or no eutectic liquid during solidification.

It is especially common in high-purity commercial solid-solution type aluminum-base alloys containing magnesium and/or zinc, and in the high-purity binary alloy containing up to about 4.5 per cent of copper. It is also common in many copper-base casting alloys, in which it is known variously as "oxidation," "shrinkage," "gas porosity," and "incipient shrinkage."

The appearance of microporosity in magnesium alloys is illustrated by the accompanying figures, which show it by means of X-ray and by photomicrographs. Specifically, microporosity, as shown by Fig. 10, consists of small voids more or less interconnected to form colonies, the

• ***Laboratory and production foundry tests results indicate that the occurrence of microporosity in magnesium alloy castings may be markedly reduced by the use of melt degassing methods described in the paper.***



Specimen No.	84A	90A	101B	76D
Height of sound Metal, inches	1⅜	2¼	2⅞	3½

Fig. 5—Radiographs of sections cut from wedge casting showing various heights of sound metal, corresponding to variations in gas content of melts.

individual voids being visible only under a microscope, but the colonies may be visible with a naked eye on carefully machined, ground, or polished sections. The individual voids usually lie between the grains, but may occur between the axes of the dendrites forming the grains.

After the castings have been heat treated, the fractures through sections containing microporosity are discolored, the shade of the discoloration depending upon the amount of the microporosity. In general, the color has a slight tinge of straw yellow when the microporosity is not severe, the color increasing in intensity through brown, gray, and black with increasing amounts of the unsoundness. This unsoundness has an adverse influence on the mechanical properties, the effect on the properties of test bars cut from castings being as follows:[1]

	Relative Value	
Color of Fracture	*Tensile Strength*	*Elongation in 2 in., per cent*
Clean, sound	100	100
Pale yellow	78	70
Brown	68	60
Gray, black, purple	50	30

This adverse effect of microporosity on the tensile properties is very serious indeed, and while no data are at hand, it is quite likely that the adverse effect on the fatigue life would be even more severe. This would be expected because the microporosity forms angular discontinuities, a form of defect which acts as a stress raiser in the casting.

In view of the occurrence of microporosity in commercial castings which are considered to be of fairly good quality, it is evident that the problem is a serious one and merits considerable attention on the part of both the user and the producer of magnesium castings.

Practical Methods of Measuring Degree of Microporosity

There is no reliable method of precisely measuring the degree of microporosity in a casting, but there are methods of roughly estimating the severity of the defect. These methods are (1) fracturing the casting after heat treatment, (2) preparing sections of the casting and observing the unsoundness under the microscope or revealing the unsound areas by using oil and chalk, and (3) X-raying the casting.

The first two methods are destructive and, therefore, have their limitations. They are both thoroughly reliable, but they show the degree of unsoundness only on the section fractured or polished. The X-ray method does not have the limitations of the first two methods, but, unfortunately, radiography is not too reliable unless its limitations are realized and the results are intelligently interpreted.

The X-ray shows the microporosity reliably and very well when dealing with reasonably thin sections which lend themselves to good exposures. Unfortunately, most commercial castings are too complicated for good X-ray "shots" and, under

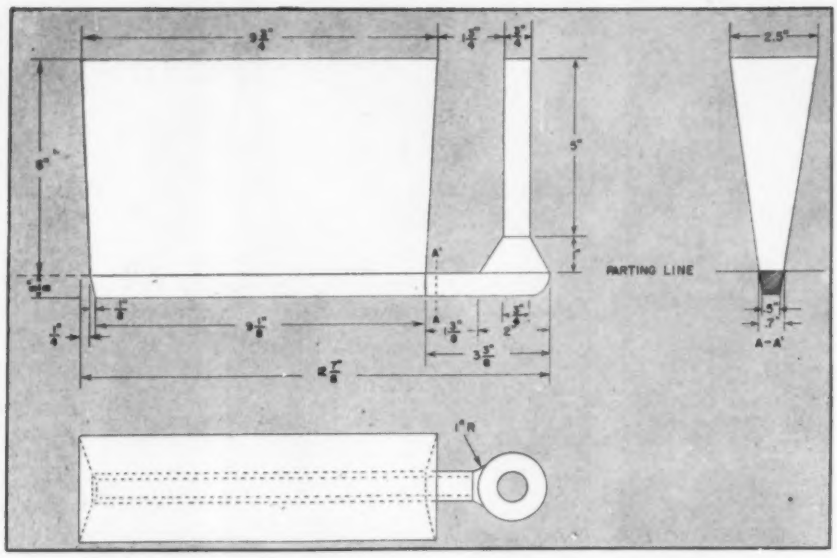


Fig. 1—Views of the wedge casting used in the investigation.

these circumstances, the X-ray may provide a clean bill of health for the sections which are difficult to X-ray, but show unsoundness where the X-ray exposure is more favorable. Even with good exposures, only severe cases of microporosity may be discovered in heavy sections.

Because of these limitations and the expense involved, many foundries rely mostly on the fracture test to determine the quality of the castings in respect to the occurrence of microporosity. This may be done by (1) fracturing a certain percentage of production, say every twentieth casting, regardless of whether or not the casting is scrap, or (2) fracturing all or a portion of the scrap, since this can be safely assumed to be representative of the production in respect to the occurrence of microporosity.

Since the microporosity shows on the fracture as a discoloration after heat treatment only, the solution heat treatment must precede this test. Also, because aging makes the castings more brittle, the fractures will be smeared less if the aging treatment has been carried out. Most foundries use a hydraulic press or a mechanical shear for the fracture operation, both machines requiring wire shields for the protection of the operator.

Experimental Methods

Melting and Molding Procedure

All melts were made in 60- or 130-lb. steel pots in a gas-fired furnace, using regular commercial melting methods, except as noted in the data. The molding sand consisted of a synthetic green sand prepared by mulling washed Ottawa silica sand with 4 per cent of bentonite, 5 to 6 per cent of inhibiting agent No. 190, 1.5 per cent of ethylene glycol, and about 2 per cent of water. This sand had an A.F.A. permeability of 95 to 110 and about 9 psi. compressive strength. Molds were made by jolting to a mold hardness of about 60.

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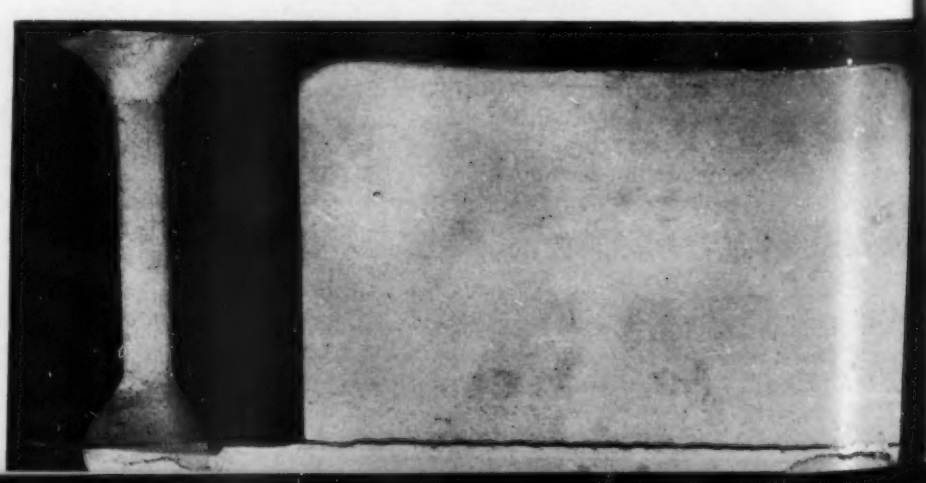
Early in the experimental work, it was discovered that a considerable variation in the amount and location of microporosity occurred in a wedge casting being used to provide bars for certain mechanical tests. This led to an investigation of the causes of these variations as a first step in the experimental program, and the wedge casting and the 4-bar pattern were used for this phase of the work. The wedge casting is shown by Figs. 1 and 2; the test-bar casting by Fig. 3.

The susceptibility of the melt to form microporosity in the wedge casting was determined by cutting a vertical section ½ in. thick from the center of the wedge, smoothing the surfaces and revealing the microporosity by using the chalk and oil method, or by X-raying the section. Since these sections are ideal for X-raying, this method, checked by the oil-chalk method, was employed to show the amount and distribution of the microporosity.

Figure 4 shows the distribution of microporosity in the wedge casting poured from a good quality melt, i.e., one which produced about 3½ in. of sound metal in the bottom of the wedge. The gate was at the end marked on the X-ray film, and it is evident that less microporosity occurred in this portion, but its distribution is otherwise uniform throughout the length of the wedge.

The vertical ½-in. section cut from the center of the wedge, therefore, may be regarded as being representative of the casting. Melts varied considerably in respect to height of sound metal in the bottom of the wedge. This variation was found to be from 0 to about 3½ in., depending upon the melting technique and melt treatment. These variations in melt quality as represented by their susceptibility to form microporosity are shown by the photographs of

Fig. 2—Photograph of the wedge casting used to measure the susceptibility of the melt to the formation of microporosity.



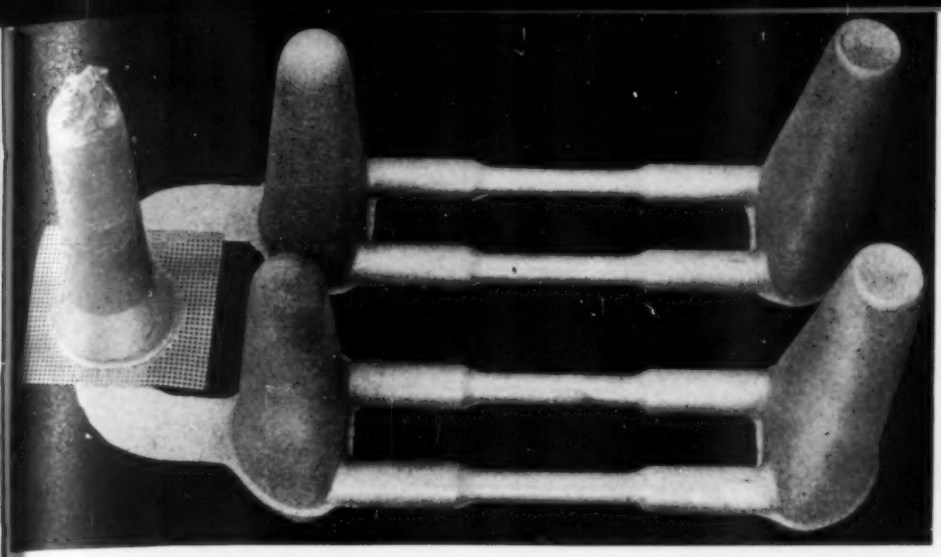


Fig. 3—Photograph of the four-bar pattern test-bar casting.

X-ray films presented in Fig. 5.

The section at the left in Fig. 5 was poured from a gassy melt very subject to the formation of porosity, in this instance macroscopic in size. The melt quality improves successively from left to right, the last one having 3½ in. of sound metal at the bottom of the wedge. This amount of sound metal was about the best that could be obtained in the wedge casting except by the employment of special means, such as by using an air vibrator on the mold or exothermic compounds on the risers.

It was found that the test bar properties did not reflect the melt quality in the range encountered in this work unless the melt was deliberately gassed. Since all of the test bar properties were very good, unless they were poured from purposely gassed metal, no test bar data are listed in this paper.

Gas in Magnesium Melts

The possibility was investigated that dissolved gas in the melt might account for the variation in the susceptibility of the metal to microporosity in the wedge casting. In view of the strongly reducing nature of molten magnesium, it is not likely that such common gases as CO, CO_2 and SO_2 would be the cause o much trouble, for these gases would be decomposed by reduction.

Nitrogen forms a stable nitride, and it also is not likely to be a cause of difficulty from gas evolution during solidification. However, magnesium melts, like those of aluminum, might dissolve hydrogen. Winterhager[2] tentatively found that the solubility of hydrogen in magnesium was as shown in Table 1.

Table 1 are remarkably high and would warrant checking. Magnesium alloy melts generally are considered to be free of gas absorption difficulties, probably because no macroscopic evidence of gas, such as pinholing, occurs in the castings. A very considerable amount of evidence has been accumulated that magnesium alloy melts can and do absorb hydrogen, and this is amply demonstrated by the experimental results described in the following paragraphs and by the photograph (Fig. 11).

Table 1

SOLUBILITY OF HYDROGEN IN MAGNESIUM

Temperature, °C.	*H_2 per 100 grams Metal, cc.*
650 solid	18
650 liquid	26
700 liquid	26
800 liquid	27
900 liquid	31

Experimental Work

The Effect of Hydrogen Additions

A number of heats were prepared whereby careful melting methods were used to avoid gas absorption and to provide a good quality of metal. A control wedge was then poured, for purposes of comparison, to show the height of sound metal in the wedge prior to the special treatment. The remaining melt was then treated in various ways to add hydrogen to the melt, after which another wedge was poured.

Sections from the wedges were cut and X-rayed as decribed previously, and the relative soundness, i.e., the height of sound metal in the bottom of the wedge, was measured. Using ASTM-4 alloy, the effect of gassing the melt was found to be as indicated by the data provided in Table 2.

These data clearly show that if ordinary tank hydrogen is bubbled through the melt, the wedge poured from it will contain more microporosity than the wedge poured before the hydrogen addition. Apparently, also, it is the moisture in the hydrogen rather than the molecular hydrogen which causes the gas absorption. This is a characteristic of biatomic gases, for, if they are produced in atomic or nascent form,

Fig. 4—Radiograph of the wedge casting showing the distribution of microporosity represented by the dark, cloudy areas on the photograph.

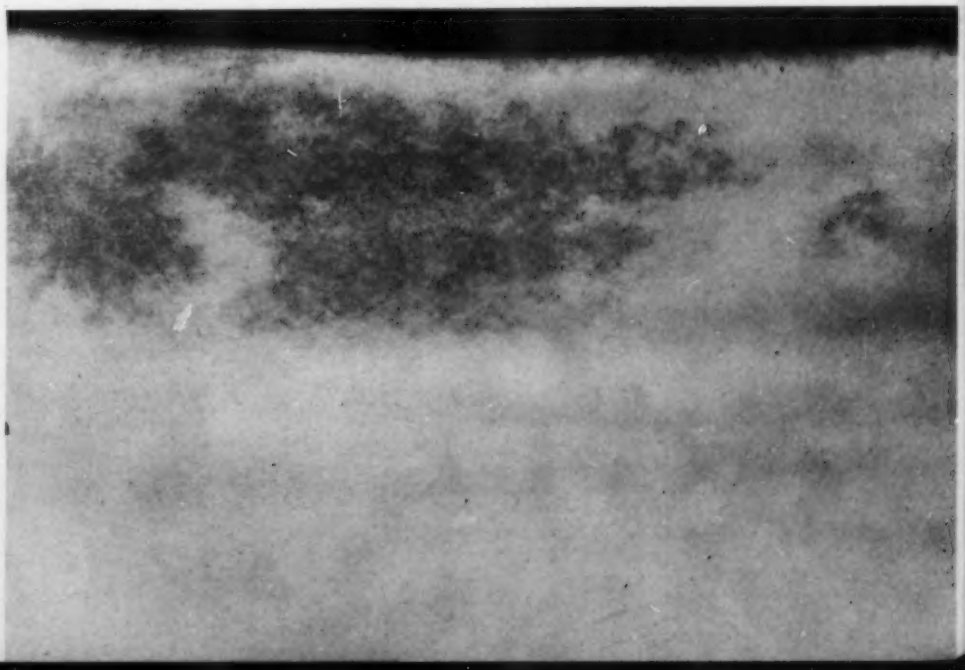


Fig. 6—Radiographs of section of turret casting, ASTM-4 alloy, are representative of regular production of this part in this commercial foundry. Height of sound metal in a wedge poured from same heat was only 3/8 in. Compare with Fig. 7.

they are much more active than the molecular gas.

The atomic or nascent hydrogen is produced by the reaction

$$Mg + H_2O \rightarrow MgO + 2H.$$

The H is very active, whereas H_2 is not sufficiently dissociated at the temperature of the magnesium melt to be absorbed to any noticeable extent by the 5-min. treatment in Heat 97.

Other sources of atomic hydrogen, such as NH_3 and metallic hydrides, also gas the melt and markedly decrease the height of sound metal in the wedge. This is illustrated by the data in Table 3.

These data clearly show that atomic hydrogen supplied as moisture, ammonia, or as metallic hydrides will, if added to the melt, greatly increase the amount of microporosity as measured by the height of sound metal in the wedge casting.

If it now be granted that an increase in the amount of hydrogen, apparently in atomic form in the melt, causes an increase in the amount of microporosity, the question then becomes a dual one: (1) how may the hydrogen be kept out of the melt, and (2) if it enters, how can the hydrogen be eliminated from the melt?

In respect to the first part of the question, the melting practice is the principal factor determining the amount of gas in the melt, which in turn reflects the amount of microporosity obtained in the casting. The importance of some of the factors encountered in the melting practice which influence the amount of gas absorption is illustrated by the data in Table 4.

The good fluxing practice consisted of dusting the refining flux on lightly while stirring the melt, or permitting the refining flux to liquify completely before it was stirred into the melt. The poor fluxing practice consisted of placing about ¼ in. of refining flux on the melt and stirring it in before it was melted, this practice being quite common in commercial foundries.

The manner in which the refining flux is stirred into the melt is very important because the commercial fluxes contain up to 10 or 15 per cent and rarely less than 4 per cent of water. The fluxes are also strongly deliquescent and may absorb considerable water if the flux containers are permitted to stand open in the melting room for any length of time.

It is a characteristic of these fluxes that considerable water may be absorbed, even at slightly elevated temperatures, with the flux still re-

Table 2

EFFECT OF HYDROGEN ON OCCURRENCE OF MICROPOROSITY

Heat No.	*Treatment of Melt*	*Height of Sound Metal in Wedge, in.*	*Grain Size, in.*
82A	Melted, using good practice	3 3/4	0.005
B	Tank H_2 bubbled through melt at 1400° F. for 5 min.	0	0.004
83A	Melted, using good practice	3 1/8	0.007
B	Tank H_2 bubbled through water, then into the melt at 1400° F. for 5 min.	0	0.004
97A	Melted, using good practice	2 9/16	0.012
B	Dried H_2 bubbled through melt at 1400° F. for 5 min.	3 1/2	0.010

maining dry and powdery. It is only when very large amounts of water are absorbed that the flux cakes up or feels damp. If the fluxes are stirred into the melt before they have an opportunity to dry out on the melt surface, or if the melt is poured through a layer of flux, the moisture so introduced into the melt will gas the metal.

In addition to the (1) moisture in the flux, there are, of course, other sources of moisture which may gas the melt, these being (2) moisture on the surface of the metal charge, (3) moisture on the surface of tools and pots if they are not preheated sufficiently, particularly if they are covered with flux, (4) moisture naturally occurring in the atmosphere, (5) moisture from the products of combustion, and (6) atmospheric moisture which contacts the melt during the pour or that which is in the sand and contacts the liquid melt before solidification occurs.

No difference has been noted in the occurrence of microporosity in the wedge or in 5/32-in. plates cast in green sand or core sand. Both sands have A.F.A. permeabilities in excess of 100, and the moisture content of the green sand was about 2 per cent. However, unsoundness similar to ordinary microporosity is frequently found in fairly heavy sections near the surface adjacent to either green sand or core sand (Fig. 12).

This possibly is caused by local hydrogen absorption and reprecipitation without general diffusion throughout the casting. If so, this hydrogen probably originates by the oxidation of the metal by the moisture or other oxidizing materials in the sand, the latter occurring especially in core sands. This oxidation should be associated with sand reaction or burning, accompanied by the liberation of hydrogen which is locally absorbed and reprecipitated, forming microporosity as described elsewhere. Consequently, this surface microporosity should be accen-

Table 3

Effect of Other Sources of Atomic Hydrogen on Occurrence of Microporosity

Heat No.	*Treatment of Melt*	*Height of Sound Metal in Wedge, in.*	*Grain Size, in.*
81A	Melted, using good practice	2 3/4	0.012
B	Nitrogen bubbled through water, then in the melt at 1400° F. for 5 min.	1 1/2	0.010
85A	100 per cent scrap melted using good practice, except scrap was not dried	1	0.006
B	0.25 per cent zirconium hydride added at 1400° F.	0	0.008
86A	Melted, using good practice	3 3/8	0.006
B	0.28 per cent titanium hydride added at 1400° F.	9/16	0.007
87A	Melted, using good practice	2 1/8	0.020
B	0.25 per cent calcium hydride added at 1400° F.	1/8*	0.045
89A	Melted, using good practice	2 3/4	0.020
B	Steam bubbled through melt at 1400° F. for 5 min.	1/4	0.012
93A	Melted, using good practice	3	0.012
B	NH_3 bubbled through melt at 1400° F. for 5 min.	1/4	0.015
100A	Melted, using good practice	3 15/16	0.007
B	NH_3 added while heating from 1300 to 1600° F.	13/16	0.006

*See this specimen, 87B, Fig. 5.

Table 4

Effect of Melting Practice on Occurrence of Microporosity

Treatment of Melt	*Number of Melts*	*Height of Sound Metal in the Wedge, in.* Min.	Avg.	Max.
Good melting and fluxing practice	34	1 1/2	2 3/4	3 15/16
Poor fluxing practice	8	0	3/4	1 3/4
100 per cent scrap, good melting practice	4	1 7/8	2 7/8	3 1/2
100 per cent scrap, not dried, but otherwise good melting practice	4	1/4	1 1/8	1 3/4

Fig. 7—Radiographs of same section of turret casting shown in Fig. 6 when made from chlorine-fluxed metal. Improved soundness of this metal over that shown in Fig. 6 is obvious. Height of sound metal in wedge poured from same heat was 3½ in.

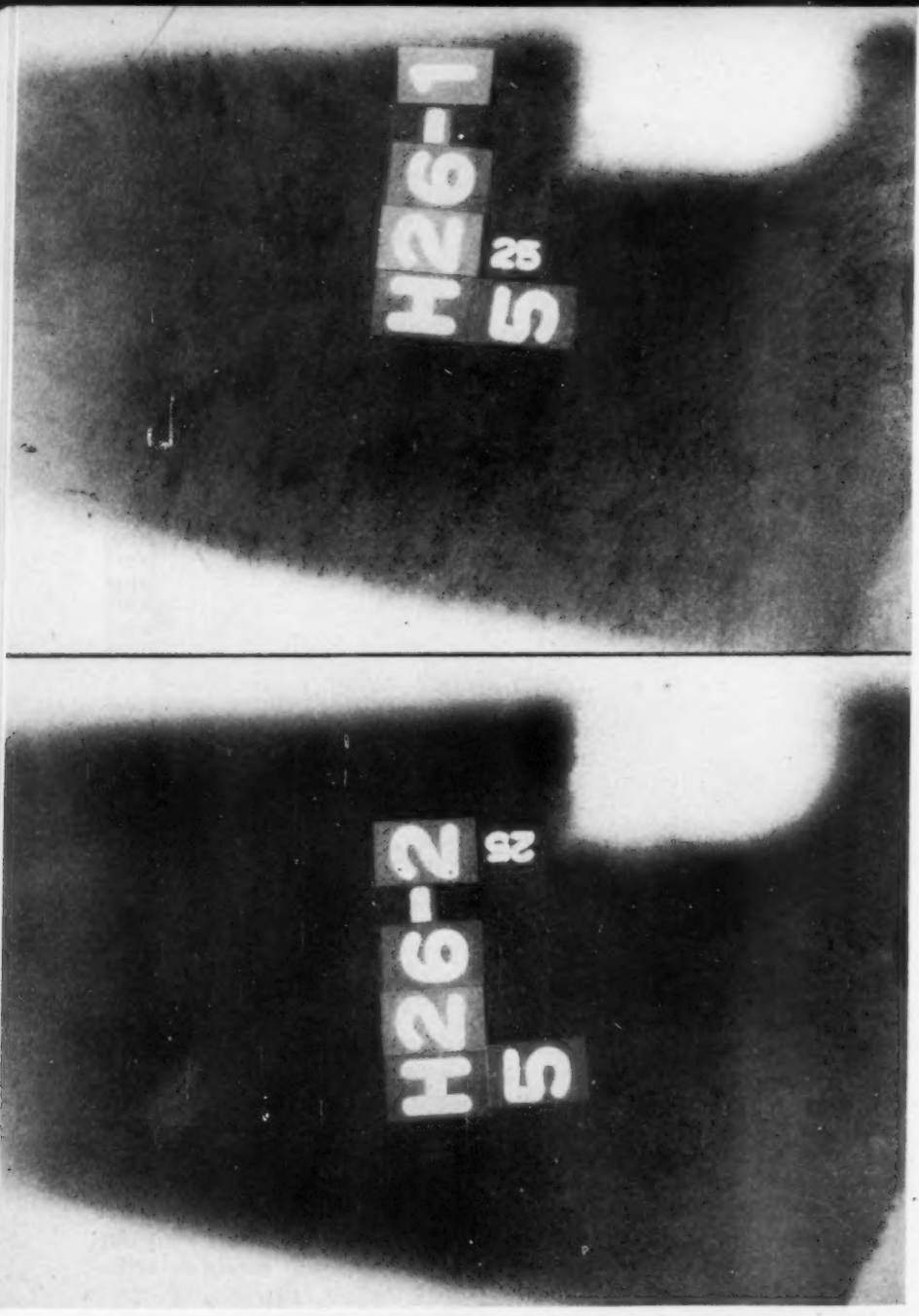


Fig. 8—Radiographs (Figs. 8 and 9) show microporosity in a gear housing, ASTM-17 alloy, and are representative of regular production of this aircraft part in a second foundry. Fig. 9—ASTM-17 alloy. Same as part shown in Fig. 8 except that metal was fluxed with Cl_2. Reduction in microporosity effected by cleaning and degassing operation is evident.

tuated by high pouring temperatures, heavy sections, low inhibitors, and high moisture content of the sand.

Several experiments have been made, but it has been found that the occurrence of the microporosity in the wedge adjacent to the sand surface apparently bears no relationship to either the moisture or inhibitor content of the green sand used.

The moisture on the surface of the metal may be absorbed on the surface or as part of the corrosion products on the ingot or scrap. This is an important gas source which can be avoided, partially at least, by the following practice:

(1) By not permitting corrosion to occur on the scrap or ingot, this being effected by proper housing and by avoiding long storage periods.

(2) By preheating the charge thoroughly, this being effected by preheating the metal to 400 or 500° F. in a separate oven, or preheating the metal carefully on the furnace edge and charging each addition onto that previously charged but which is not yet melted.

The data in Table 4 clearly show the reduction in microporosity effected by preheating the scrap metal used in the charge.

The application of good safety rules requires preheating of pots and tools before they are permitted to come in contact with liquid magnesium, so that this gas source is not important. Gas absorption by permitting the melt to fall in a thin stream through the atmosphere is quite possible, but it can be avoided by keeping the ladle lip near the pouring box and pouring rapidly.

The moisture in the atmosphere, either that in the products of combustion in the gas or oil-fired furnace or that naturally occurring in the atmosphere, is difficult to avoid. A degassing operation after melting is about the only solution to this problem but, as the foregoing data indicate, a considerable reduction in microporosity can be effected by good melting and fluxing practices.

Removal of Hydrogen from the Melt by Using a Fluxing Gas

While good melting and fluxing practices are markedly beneficial in respect to the reduction of microporosity, it has been found that consistently better melt quality can be attained by combining good melting and fluxing practices with a degassing treatment, either coincident with or just preceding the grain-refining treatment. If superheating is used, this operation must follow the degassing treatment.

A common method of degassing melts, particularly those of aluminum-base alloys, consists of bubbling a suitable gas through the melt. While the action of such a gas may be in part chemical, it is probable that such a fluxing material acts as a mechanical carrier, the dissolved gas in the melt "desorbing" on the bubble of fluxing gas, the latter then carrying it to the melt surface where it can escape. Suitable fluxing gases for aluminum are chlorine, nitrogen, helium, and vapor from many solid and liquid materials, particularly chlorides.

Some of the results obtained by degassing by bubbling various gases through the magnesium ASTM-4 alloy melts are listed in Table 5.

In addition to the treatments listed in the foregoing data, SO_2 and sulphur vapor were tried, but they did not show much promise. Likewise, certain dried carbonaceous

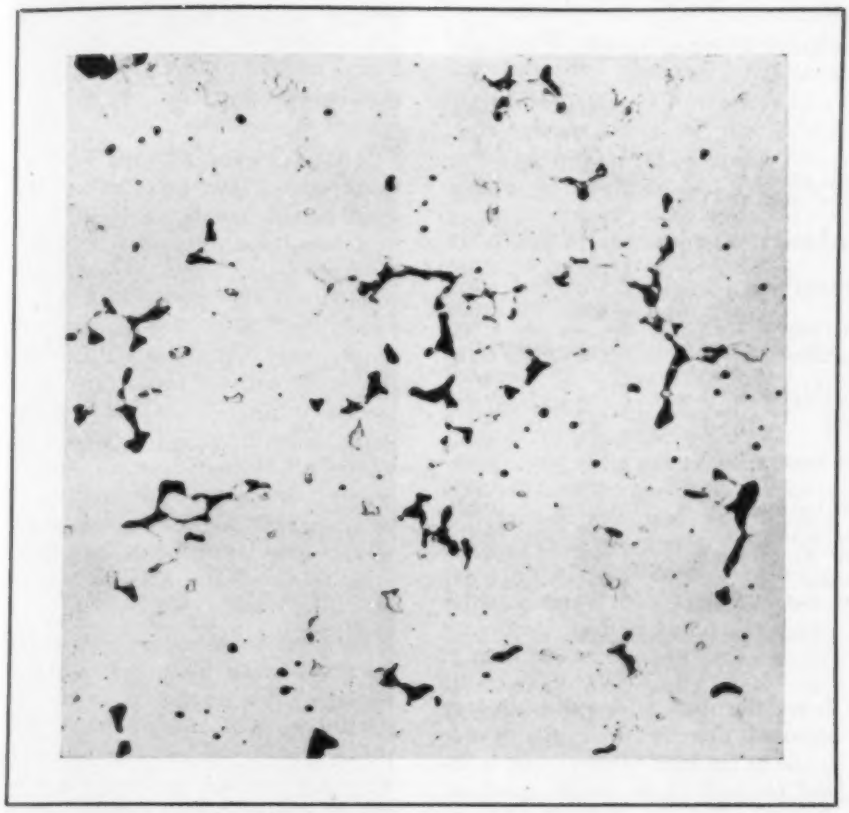


Fig. 10—Photomicrograph showing typical microporosity in ASTM-4 alloy casting. Magnification, X100.

gases, such as acetylene, CO_2, and natural gas were tried and, while they do not show much promise as degassers, they have a beneficial effect, as reported separately.[3]

The data in Table 5 show that dried gases such as argon, helium, and nitrogen do not show much promise, while a chlorine treatment has a markedly beneficial effect. The chlorine is used in place of the usual "cleaning" operation of stirring in a refining flux.

When chlorine is used, the metal is melted, employing the usual melting flux, then chlorine is passed through a carbon tube into the melt for 15 min. at a rate such that the melt temperature during the chlorine treatment may be 1250 to 1450° F. Some slight burning may occur during this operation, particularly if the melt temperature is 1400° F. or above, but this is readily eliminated by a light sprinkle of refining flux.

The previously outlined procedure for the use of chlorine has been adopted as standard practice in all the experimental work, and scores of melts so treated have amply confirmed the reliability of the data on chlorine treatments listed in Table 5.

Commercial Foundry Tests

The laboratory results on the use of chlorine have been checked in two commercial foundries making aircraft parts. Several melts weighing up to 300 lb. were treated; in one foundry, wedges and miscellaneous aircraft parts were poured from melts (1) fluxed for 15 min. with chlorine, (2) melted using the melting precautions outlined previously, and (3) prepared by regular production methods.

In the second foundry, chlorine-fluxed and regular production melts were poured into aircraft parts, and quality comparisons were made. In each instance, the laboratory results were verified and typical radiographs of castings from regular production and chlorine-fluxed metal are shown by Figs. 6 to 9, inclusive.

Some concern was felt over the possibility that the $MgCl_2$ formed by the chlorine might cause flux inclusions. This chloride apparently separates from the melt very well, and no flux inclusions could be noted on the aircraft parts placed in a humidity room for several days.

A second common method of degassing aluminum alloys consists of melting, solidifying either in the pot

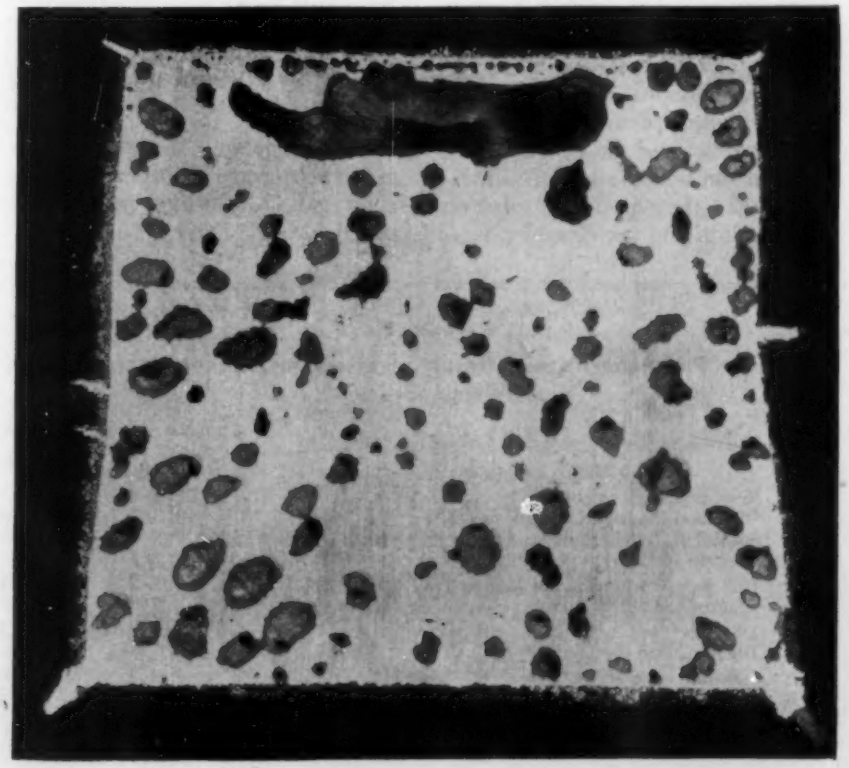


Fig. 11—Photograph of section of 4-in. cube, no riser, poured from ASTM-4 alloy melt which had been severly gassed with C_2H_2. Large cavities formed by hydrogen precipitated when melt solidified are ample evidence of the considerable hydrogen solubility in magnesium melts.

Table 5

REDUCTION OF MICROPOROSITY BY BUBBLING VARIOUS GASES THROUGH 40- TO 60-LB. MELTS OF ASTM-4 ALLOY

Heat No.	Metal Treatment	Height of Sound Metal in Wedge, in.	Grain Size, in.
80A	100 per cent scrap, melted using good practice	3	0.020
B	N_2 from tank bubbled through the melt 5 min. at 1400° F.	2 1/2	0.030
96B	Melt gassed with zirconium hydride	1/8	0.010
C	Dried N_2 bubbled through the melt at 1400° F. for 5 min.	3/16	0.015
99A	100 per cent scrap	1 13/16	0.010
B	Dried argon bubbled through melt at 1400° F. for 5 min.	1 3/8	0.007
106A	ASTM-4 alloy without Mn	1/4	0.008
B	Dried helium bubbled through melt at 1400° F. for 5 min.	0	0.008
133A	100 per cent scrap, poor fluxing practice	1/2	0.010
B	Dried helium bubbled through melt at 1400° F. for 5 min.	1 1/4	{0.004 0.008
C	Melt superheated, commercial practice	1/2	0.007
84A	100 per cent scrap	1 3/8	0.008
B	Cl_2 from tank, bubbled through melt at 1400° F. for 5 min.	2 7/8	0.006
100B	Melt gassed with NH_3	1/2	0.006
C	Cl_2 bubbled through melt at 1300° F. for 5 min.	13/16	0.006
115A	100 per cent new ingot, poor fluxing practice	1/8	0.010
B	Cl_2 bubbled through the melt at 1400° F. for 6 min.	1 3/4	0.005
125A	100 per cent scrap, poor fluxing practice	0	0.007
B	Cl_2 bubbled through the melt at 1400° F. for 15 min.	3 1/2	0.006

or by pigging the melt and then remelting. The decrease in solubility during solidification causes the precipitation of hydrogen in the form of H_2, which is not readily reabsorbed. If the conditions are such during the remelting operation that gas absorption is avoided or reduced, some degassing can be effected. The results of some laboratory tests are shown by the data given below in Table 6.

The foregoing data indicate that, under these conditions of melting, some decrease in microporosity can be effected by presolidification. Many foundries use this method to degas the gassy melts sometimes encountered when remelting poor quality scrap. In such instances, the high gas content will cause a high convex set on top of the risers, as is shown by the data on specimen 87B of Fig. 5.

The effects of pouring temperature, superheating, and grain size on the degree of microporosity have been investigated in the wedge castings and in horizontally cast plates. It has been found that very low pouring temperatures tend to accentuate microporosity, while wide variations in the normal pouring range have no noticeable effect on the amount or distribution of this defect.

Although the hydrogen solubility increases with increasing temperature, it has been found that the superheating operation does not accentuate microporosity, probably because the melt is not disturbed or exposed directly to a gas source while at the high temperature, it being encased in its oxide envelope. On the other hand, there is some evidence that a marked decrease in grain size reduces the susceptibility to microporosity to a slight extent.

Mechanism of Microporosity Formation

The role of gas in the formation of microporosity seems well established, particularly so since experience has shown a similar relationship in other solid solution types of alloys of different base materials.[6] A general description has been made[4] of the mechanism of the formation of microporosity, and the effects of (1) range in the temperature of solidification, (2) the amount of eutectic liquid solidifying at constant temperature, (3) the temperature gradients during solidification as determined by the gating, risering, and chilling practice, and (4) the gas content of the melt.

It seems logical that the voids of microporosity are initiated by the shrinkage or contraction of the melt during solidification of the latter portion of the liquid. These voids would normally be filled with liquid, but in the solid solution alloys, the mushy zone makes this difficult. If the melt contained no gas, the voids would be under a vacuum, the absolute pressure of which would be equal only to the vapor pressure of the melt at the temperature in question. If this were true, the voids would draw liquid metal into them as a result of the exterior atmospheric pressure.

However, if the melt contains a gas in solution which is precipitated during solidification, as is usually the case, these voids are gas filled, and this condition prevents the entrance of metal into the voids. This condition is akin to that existing when trying to pour a liquid into a narrow necked bottle. Microporosity, then, may be regarded as being initiated by shrinkage, but the gas in the metal may prevent the resulting voids from being fed.

On the basis of the foregoing remarks, and on those cited in Reference 4, it is evident that microporosity can be reduced by effecting the following conditions:

(1) Reducing the gas content of the melt.

(2) Steepening the temperature gradients toward the risers by using good gating, risering, and chilling practice.

Table 6

EFFECT OF PRESOLIDIFICATION ON OCCURRENCE OF MICROPOROSITY IN THE WEDGE CASTING

Heat No.	Metal Treatment	Height of Sound Metal in Wedge, in.	Grain Size, in.
76A	New ingot, as melted	2 3/4	0.015
B	"Cleaned" with No. 310 flux	2 3/8	0.010
C	Solidified in the pot and remelted twice	2 3/8	0.008
D	Superheated	3 1/2	0.004
77A	100 per cent scrap, as melted	2 1/2	0.005
B	Ingoted and remelted	2 7/8	0.008
78A	100 per cent new ingot, as melted	1 7/8	0.025
B	Ingoted and remelted	3	0.007
101A	100 per cent scrap, "cleaned" with No. 310 flux	2 3/8	0.008
B	Solidified in the pot and remelted twice	2 7/8	0.012
56	Melted, solidified in the pot and remelted twice under a No. 230 flux	3	.....

Fig. 12—Radiograph of wedge casting section showing microporosity at the edge next to the green sand. This is not uncommon in heavy sections of magnesium alloys cast in green or dry sand, and probably represents local absorption of gas generated as a result of initial stage of sand reaction.

(3) Using an alloy composition which will be least susceptible to microporosity.

Only the first of these has been described in this paper, the second encompasses the entire gating problem, a discussion of which has not been attempted, while the third part has been covered as a part of a separate paper.[5]

Summary

Extensive laboratory tests checked by production foundry results have clearly shown that, all other factors being the same, microporosity in magnesium alloy castings is markedly reduced by degassing the melt and greatly increased by exposing the melt to any condition which produces atomic hydrogen. The most common source of atomic hydrogen is moisture, and the common sources of moisture are listed in their probable order of decreasing importance as follows:

(1) In the flux.

(2) Absorbed on or in chemical combination with the metal surface as part of the corrosion products.

(3) In the surrounding atmosphere, either in the products of combustion or naturally occurring in the atmosphere.

(4) In the atmosphere or in the sand and absorbed during the pour and before it solidifies in the mold.

(5) On pots and tools not thoroughly preheated and which come in contact with the melt.

The methods of reducing gas absorption from some of these sources during melting are described. The best method found for degassing and removing dross from the melt is by fluxing the melt with chlorine instead of performing the standard "cleaning" operation with a refining flux. Presolidification was also found to be beneficial, although slow and uneconomical.

Acknowledgment

To the Office of Production Research and Development of the War Production Board, which sponsored the work described in this paper and granted permission for its publication, to the Office of Scientific Research and Development, which guided the work, to members of the Advisory Committee on Project NRC-546, and to many members of the staff of the Battelle Memorial Institute, especially Messrs. C. H. Lorig, C. T. Greenidge, and A. R. Elsea for their valued assistance, the authors gratefully express their thanks and appreciation.

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Fig. 1—Upper half of high pressure turbine casting. Markings indicate areas designated for magnetic particle and gamma ray inspection.

Removal and Repair of STEEL CASTING *Defects*

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NON-DESTRUCTIVE tests, in conjunction with repair welding of castings, have been in use on an increasingly large scale at the Quincy shipyard for the past 10 years. The reasons for the apparent misplacement of the inspection facilities at the plant of the consumer rather than at that of the producer of the castings can be summarized as follows:

1. Originally, radiographic tests were not required for all castings in a given service, but only for those castings in which major defects were discovered during machining. Thus, the inspection facilities were first installed at the plant where the castings were machined.

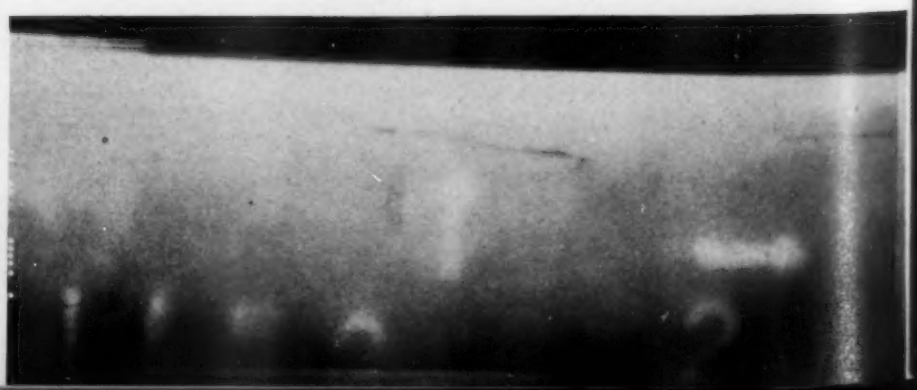
2. When general radiographic inspection of castings for a given service was required, the exposure times required for gamma ray technique were of such length that a considerable time saving could be gained by inspecting the thinner walls of a rough machined casting.

The present practice of requiring general radiographic or magnetic particle inspection for castings in which quality must be assured, as well as the use of high voltage x-ray and improved gamma ray technique, has largely nullified the reasons for placing the inspection facilities at the plant of the consumer; and we now find foundries cooperating in the effort to produce dependable castings by setting up non-destructive testing facilities and furnishing completely inspected and repaired castings which can be machined and installed in service without difficulty.

The increased use of these searching inspection methods naturally has resulted in a corresponding increase in the number of repair welds necessary, which is reflected in the increased cost of the finished casting. This cost can be reduced only by improving repair methods or by reducing the number of casting defects.

Repair costs have been already greatly reduced by the use of flame gouging, in lieu of chipping, for the removal of defects preparatory to welding, and the most promising field for further cost reduction appears to be in reducing the number of casting defects by the foundries. These inspection methods should be useful tools for this purpose, if their results are properly interpreted and applied in the improvement of foundry technique and in recommendations for design alterations.

• Flame-gouging and welding as means of removal and repair of structurally unsound areas in critical castings have reduced casting repair costs. The more searching inspection methods now in general use have shown that repair welding can be eliminated to a great extent by provision for sub-sectioning and weld location in the casting design. Flame gouging-welding techniques for casting repair, as well as precautions to be observed, are described in detail.



This paper was secured as part of the program for the 1945 "Year-Round Foundry Congress" and is sponsored by the Steel Division of A.F.A.

Fig. 2—Radiograph showing shrinkage area in side wall of by-pass valve.

Casting Defects

For the purposes of this discussion, "defects" will be considered only as structurally unsound areas which are required to be repaired under the *Navy Department Radiographic Standards,* or by similar codes. Routine dressing of the surface for improvement of appearance will not be considered. The welding technique followed in the repair of castings is discussed only insofar as it differs from normal welding.

In order to illustrate the methods of removal and repair followed at this yard, there has been selected a replacement turbine casting of old design wherein the foundryman did not have advantage of the subsectioning methods now commonly used in designing castings of this type. The likelihood of finding defects for illustration was increased.

Unfused Chills

The casting selected is shown in Fig. 1. Radiographic inspection indicated several instances of unfused chills in the flanges as well as rather pronounced shrinkage areas in the wall section of the by-pass valve. Figures 2 and 3 are typical radiographs of those sections.

The use of internal chills in castings of radiographic quality has been found to be undesirable and does not represent present-day practice, since, when they fail to fuse, the repair of the resultant defect may be more extensive than repair of the shrinkage which they were designed to avoid.

It will be noted in Fig. 4 that all flanged connections on this casting

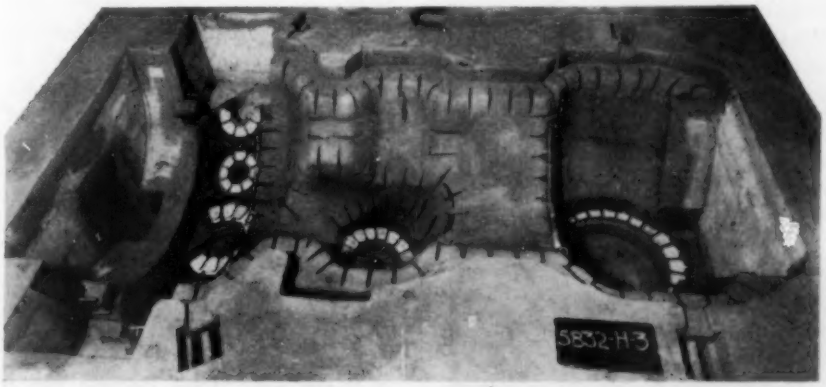


Fig. 3 (Left) — Radiograph showing unfused chills in heavy flange.

Fig. 4 (Above) — Mold for high pressure turbine casting. Note chill plates in flanged sections. This is obsolete practice, used only for purpose of illustration.

Fig. 5 (Right)—High pressure turbine casting. Shaded area indicates location of shrinkage area (see Fig. 2 radiograph).

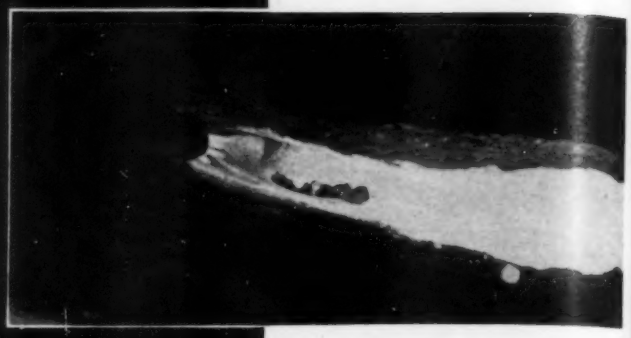


Fig. 6 (Left)—Use of standard cutting torch with flame-gouging tip in excavation of unfused chills.

Fig. 7—Close-up view of flame-gouging operation showing appearance of defect as molten metal is washed across it.

were rather heavily chilled. In the case of the by-pass flange, not only did the chills fail to fuse but the shrinkage which might otherwise have occurred in the flange extended the full length of the wall section, as indicated by the shaded area in Fig. 5.

The use of flame gouging in the removal of extensive defects of this type is particularly advantageous since the removal time usually may be measured in minutes, whereas the former method involving chipping would require hours. The equipment in use at this plant consists of a special cutting torch with flexible copper tubes and one of the bent, smaller sizes of flame-gouging tips, as shown in Fig. 6.

This operation, when properly controlled, results in the complete removal of the defect, with the removal of a minimum amount of sound metal. The defect can be seen by the operator during gouging and, therefore, it usually is possible to carry the operation to complete removal of the defect without frequent pauses for inspection.

Figure 7 illustrates the appearance of a shrinkage defect as a dark spot in the white molten metal surrounding it. Sand inclusions usually will appear as more highly incandescent areas than the surrounding molten metal.

Cracks may be more difficult to follow during the gouging operation, and sometimes may travel deeper into the casting if they are not completely removed before the flame-gouged cavity is allowed to cool. Shrinkage stresses in the cooling cavity will tend to concentrate at any remaining portion of the crack, causing it to open and extend to a greater depth.

An incompletely excavated crack usually can be seen if the cavity is examined immediately after gouging is stopped, when it will be visible in the cooling cavity. When these cracks are present, gouging should be resumed immediately in order to complete their removal before cooling has progressed sufficiently to set up stresses.

Fig. 9 (Right)—Completed excavation of shrinkage defect in by-pass wall.

Flame-Gouging

The selection of flame-gouging operators is important, an essential requirement being that they be sufficiently familiar with the subsequent

Fig. 8 (Left)—Flame-gouging shrinkage area in by-pass wall. Arrow indicates part of defect in molten stream.

welding operations to shape the excavation to a form best suited for welding. In fact, the most efficient flame gougers at this plant are the welders themselves.

Flame gouging of the shrinkage defect (Fig. 2) is shown in Fig. 8. Since a completely sound repair can be assured only when the weld is laid on a sound base metal, it is necessary that the defect be removed completely. This usually is checked by magnetic particle inspection after excavation, particularly when the defect involved is a crack or tear. In this case, the excavation completely penetrated the wall of the casting, as shown in Fig. 9.

Welding Methods

After the flame-gouged cavity was cleaned of scale and sharp corners by peening and chipping, a back-up plate was tack welded to the inner wall of the casting, covering that portion of the cavity which penetrated the wall. The casting was then turned on its side, placing the cavity in position for flat welding which permits a high quality weld at the maximum rate of deposition.

The weld was then made by starting at the bottom of the cavity, laying beads in a spiral fashion and working up the sides, as shown in Fig. 10. Each subsequent layer was deposited in a similar manner, as shown in Fig. 11, and in the sequence sketch, Fig. 12.

This type of procedure generally is used for welding larger holes in rigid sections in order to prevent welding stresses from building up and cracking the casting. By this method, the opposite sides of the cavity are not tied together until much of the weld shrinkage has already occurred.

The foregoing method is not necessarily followed near edges, or where the casting is less rigid, as in unsupported curved sections. A much faster method, which consists of a

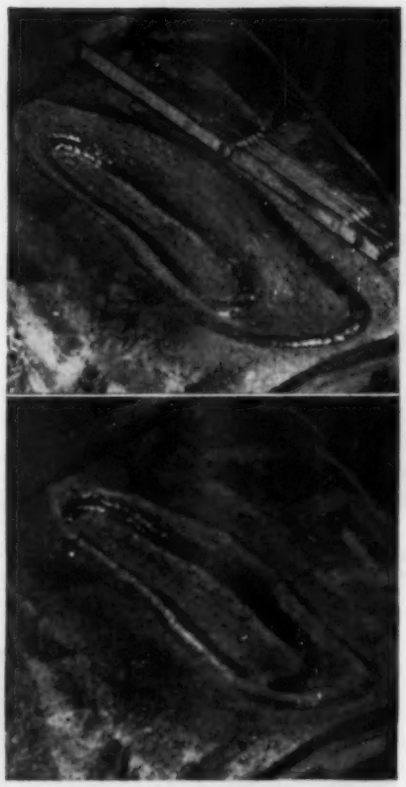


Fig. 10 (Top)—View of casting in position for welding and sequence of applying initial beads, on side walls of cavity. Fig. 11 (Bottom)—Partially completed weld showing additional layers on sides of cavities.

Fig. 12 (Below)—Sequence of bead deposition followed for welding cavities in heavy rigid sections. Fig. 13 (Right)—Sequence of depositing woven or puddled layers in welding non-rigid sections where casting is free to contract.

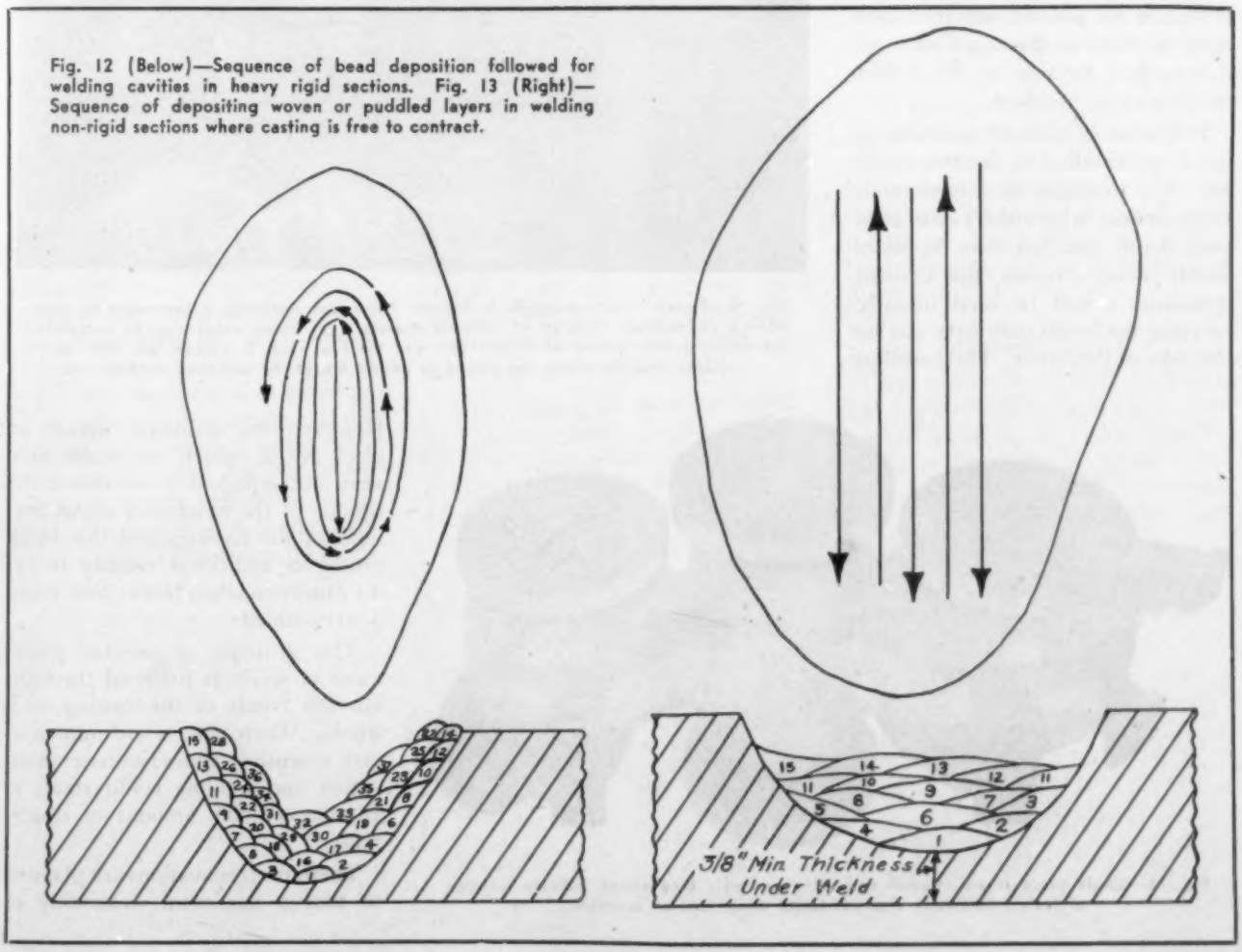


Fig. 14—Transverse defect of extended length welded in blocks in order to prevent distortion. Order of welding blocks was 2-1-3.

technique then could be used for the remainder of the weld.

Another combination of the two methods sometimes is used in the filling of a wide cavity when the weld is puddled only part way across the cavity, leaving one side free to contract, and then the final closing section is made by the beading method.

Block Welding

When the excavation of a defect produces a cavity of extended length, similar to a groove, it may be desirable to make the repair as a series of blocks rather than as a continuous weld. The transverse weld shown in Fig. 14 probably would have caused considerable bowing of the horizontal joint of the casting had it been made as a continuous weld.

puddling or weaving technique, may be used.

In this method, the beads are woven to a width of approximately 1½ in. maximum and are built up in horizontal layers from the bottom of the cavity, as indicated in Fig. 13. It should be pointed out that care must be used in the application of this method because of the higher welding stress involved.

It sometimes may be desirable to use a combination of the two methods. For example, in a moderately rigid section, where the cavity is of such depth that less than ⅜ in. of sound metal remains, the beading technique would be used initially, carrying the beads only part way up the sides of the cavity. The puddling

Fig. 15—Repair of unfused chills in flange. Note that distortion is controlled by maintaining approximate balance of welding stresses. The three welds already completed are nearly evenly spaced at about 120°, and the two welds in process are 180° apart. Side retainer plates are placed to permit use of the puddling method.

Fig. 16—Single piece steam strainer and valve casting. Excavations indicate location of tears. Shrinkage also was found under cast-on brackets.

However, the shrinkage stresses of block No. 2, which was made first, were not sufficient to overcome the rigidity of the remaining sound portions of the casting, and this block produced additional rigidity to resist distortion when blocks Nos. 1 and 3 were added.

This principle of selected placement of welds is followed throughout the repair of the casting as a whole. When defects are numerous and extensive, indiscriminate excavation and welding could result in an unacceptable amount of distortion.

Therefore, excavations are planned so that a minimum weakening of

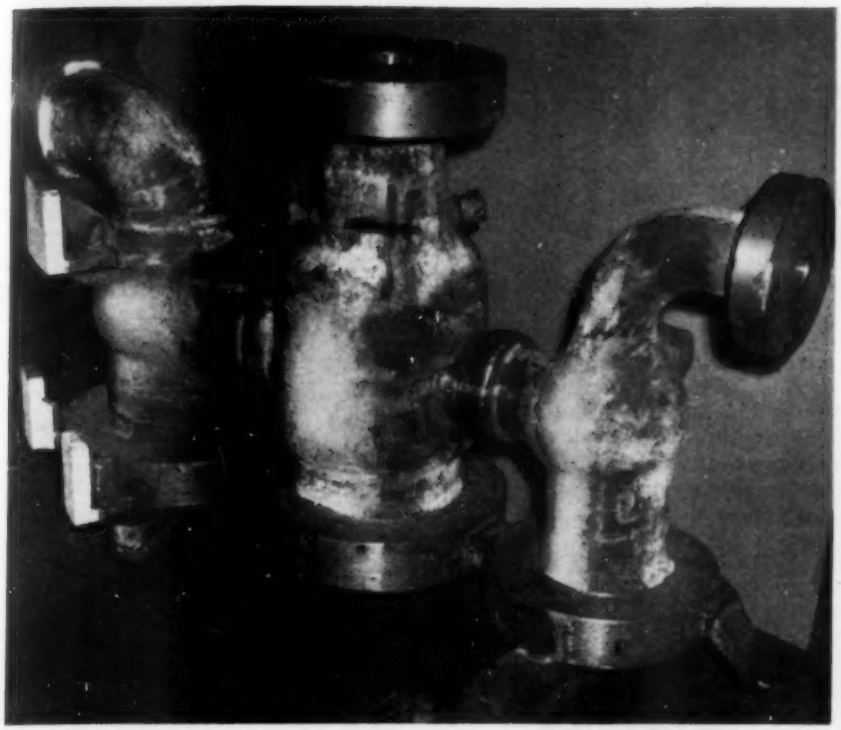


Fig. 17—Steam strainer and valve assembly made in three separate castings, with welded-on brackets and bosses.

the surrounding casting structure is caused, and defects in the metal adjacent to a cavity may not be excavated until the initial cavity has been welded. This principle is illustrated in the flange repair shown in Fig. 15. However, on rough flanges, these precautions normally would not be necessary.

Casting Design

The problem of weld location and sequence may be greatly simplified when the welds are incorporated into the design by sub-sectioning a complicated single-piece casting into two or more simpler castings. By the judicious use of welding in this way, repair welding can be eliminated to a great extent. However, effective application of this method requires closest cooperation between the foundry and the casting design agent.

In the single-piece casting shown in Fig. 16, difficulty was experienced with tears at the corners of the square pipe sections joining the center body with the two valve bodies on either side, as well as with shrinkage under the cast-on brackets. After discussion of these defects with foundry personnel, the design of subsequent castings of this type was changed to call for three separate body castings, with all brackets and bosses also cast separately.

The welding of these cast parts was comparatively simple and the need for unscheduled major repair welds was entirely eliminated. This welded assembly is shown in Fig. 17.

With regard to heat treatment, it is usual practice to employ a fairly generous preheat over the area affected by the weld when welding heavy sections. For carbon steel castings this will range from 100 to 300° F., the higher temperature being used for the thickest or most rigid sections. Excessive preheat for carbon steel should be avoided, since it has been found that an interpass temperature of above 600° F. may bring about a tendency toward porosity in the weld.

Carbon-molybdenum steel usually is preheated in the range of 300 to 600° F. Heat treatment after completion of repair welds usually consists of an all-over stress relief anneal at a temperature of 1150 to 1250° F., although some classification societies still require full annealing or normalizing and drawing.

Summary

Summarizing the points to be considered in planning the repair of castings, excavations should be planned to keep distortion from subsequent welding to a minimum. Individual defects should be excavated completely before welding is started, since unsound base metal may develop cracks in the repair weld.

In welding heavy, rigid sections, the use of preheat and the "beading" technique will aid in avoiding cracks or distortion due to excessive shrinkage. Major repairs in general should be stress relieved by heating the casting to 1150 to 1250° F. in a furnace.

Acknowledgment

The writer is directly indebted, for much of the work in connection with this paper, to E. F. Tibbetts, Engineer in charge of radiographic and magnetic particle inspection, and to A. G. Hogaboom, Welding Research Engineer.

Relative Effect of
LIME AND DOLOMITE FLUXES
On Cupola Irons and Cupola Operation

● *This report describes experiments performed to determine the effect of substituting dolomite for limestone as a cupola flux. Data are presented to show the effect of the slags on the sulphur, carbon, silicon, phosphorus and manganese contents of the irons, and on their physical properties.*

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DOLOMITE has been recommended in reports of Reese[1] and Dierker[2] as a cupola flux, lower viscosity for the magnesia-bearing slags being claimed. McCaffery and co-workers[3] published data showing a marked decrease in viscosity of three component, synthetic slags (Al_2O_3, SiO_2, CaO) produced by the introduction of magnesia in amounts of 5 to 20 per cent.

The viscosity of the magnesia slags was found to be less sensitive to changes in composition with respect to total base content than the corresponding plain lime slags. Field and Royster[4] showed a reduction in blast furnace slag viscosity with an increase in magnesia content from 1.5 to 7.5 per cent, the sum of the CaO and MgO being kept constant at 45.67 per cent.

Dierker[5] has presented some data indicating a 50 per cent decrease in sulphur pick-up by cupola cast iron when dolomite was substituted for limestone, and[2] has stated that the composition of the slag has an effect on the physical properties of the metal. McCaffery and co-workers[6] have claimed lower sulphur pig and smoother operation for blast furnaces adding dolomite flux in amounts calculated to change the mineral make-up of the slag in the furnace.

John W. Bolton in his book, "Gray Cast Iron," makes the following statement: "General opinion is that dolomite limestones are somewhat more powerful in their fluxing action, but in slags less absorbent toward sulphur than straight calcium limestones."

A cupola lined to an inside diameter of 24 in. and equipped with a constant weight blower was employed. The general procedure was to run heats in pairs, the members of each pair being the same with respect to charge, bed height, blast, etc., but differing in the flux employed, one heat being fluxed with lime and the other with dolomite.

Melting data are presented in Table 1. Each heat consisted of 12 charges. The first charge was all scrap. The remaining 11 charges were of steel, returns, and pig in the proportions given in the table.

Nine taps were made during each heat. The first tap, the all-scrap charge, was pigged. The remaining eight taps were designated alphabetically. For example, 6B indicates tap B (the third tap) from the sixth heat.

Three extra charges were made in each heat to prevent irregularities in blast and pressure during the last taps, the metal being recovered from the drop. In addition, extra coke charges were made after the last metal charge had descended the cupola stack. Coke for the bed was

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Gray Iron Division of A.F.A.

Table 1

SUMMARY OF MELTING DATA

Heat	Steel, lb.	Pig, lb.	Returns, lb.	Coke, lb.	Flux, lb.	Bed, in.	Blast, oz.	Air, lb./min.	Average Temp., °F.
1. Lime	47	135	118	37	11	40	9.2	62.5	2708
2. Dolomite	47	135	118	37	11	40	8.8	62.5	2722
3. Lime	32	165	103	43	11	42	10.3	65.0	2746
4. Dolomite	32	165	103	43	11	42	9.7	65.0	2729
5. Lime	40	152	108	43	11	43	9.4	65.0	2704
6. Dolomite	40	152	108	43	11	43	9.0	65.0	2688
7. Lime	40	150	110	43	11	43	11.1	62.5	2675
8. Dolomite	40	150	110	43	11	43	10.1	62.5	2700
9. Lime	40	135	125	43	11	40	8.6	57.0	2745
10. Dolomite	40	135	125	43	11	40	8.4	57.0	2717
11. Lime	50	142	110	60	11	42	8.2	60.0	2800
12. Dolomite	50	142	110	60	11	42	8.8	60.0	2759
13. Lime	44	112	146	43	11	42	7.2	62.5	2766
14. Dolomite	44	112	146	43	11	42	7.0	62.5	2748
15. Lime	45	110	155	43	11	42	5.7	63.0	2759
16. Dolomite	45	110	155	43	11	42	6.5	63.0	2774
17. Lime	35	190	73	43	12	43	8.5	60.0	2680
18. Dolomite	35	190	73	43	12	43	8.5	60.0	2680
19. Lime	25	145	130	43	12	40	8.4	60.0	2712
20. Dolomite	25	145	130	43	12	40	8.6	60.0	2703

Table 2

Chemical Analysis of Fluxes

	Component, per cent				
	SiO_2	CaO	MgO	R_2O_3	S
Lime	1.00	53.3	1.23	0.60	0.025
Dolomite	0.32	29.2	20.4	0.22	0.027

added and allowed to burn to redness. The bed height was adjusted by a small coke addition. A double charge of flux was added on the top of the bed.

The components of each metal charge were carefully weighed and added in the following order: steel, pig, returns. The steel was structural, cut into small pieces not exceeding ⅜ in. in thickness. Small pigs from two lots of iron were used. The pigs were broken into pieces weighing approximately 20 lb. Returns from each previous pair of heats were broken up and distributed as uniformly as possible in order to prevent variations in the chemical analysis of the charges of any one pair of heats.

Two-inch coke was used in all heats in the proportions indicated in the table. Coke from more than one lot was employed, but the coke in one pair of heats was of the same lot in all cases.

The blast was controlled with a constant weight blower. The air in lb. per min. is given in the table. The blast pressures are averages of wind box pressure readings taken during the heat.

Reference to Table 1 shows considerable variation in blast pressure between pairs of heats. This is attributed to variation in the nature of the coke and metal charges, atmosphere changes, etc. Conditions were kept constant for the members of each pair in order to eliminate these various factors as variables.

Temperature readings were taken at the spout with an optical pyrometer. The values in Table 1 are average values for the taps of each heat. Practically all temperature readings were in the range of 2,800 to 2,650° F.

Chemical analysis of the lime and dolomite employed are given in Table 2. The flux was added on top of each coke charge.

Two Series Run

Two series of heats were run. The first series, consisting of eight pairs or 16 heats, was made with the slag hole open, slagging the furnace just prior to each tap. This series consists of all heats up to and including no. 16.

The second series, of four heats, was run with the slag hole closed, allowing the slag to accumulate during the entire heat. The purpose of these heats was to determine the relative desulphurizing power of lime and dolomite slags when a heavy layer of slag was present in the cupola.

A complete chemical analysis of all the taps of a number of heats from series 1 was made. Three transverse test bars and a chill test wedge were poured from each tap of these heats. All taps of all the heats were completely analyzed for sulphur by the evolution method.

The cupola lining was restored to 24 in. after each heat, using a plastic mixture of 2 parts sand and one part fire clay.

Table 3 gives the results of sulphur determinations for the first series; Table 4, the results for the

Table 4

Influence of Lime and Dolomite Fluxes on Sulphur Content of Cupola Irons. Series 2 Cupola Not Slagged.

	Heats 17 and 18		Heats 19 and 20	
Tap	Lime	Dolomite	Lime	Dolomite
A	.098	.083	.111	.113
B	.069	.066	.085	.094
C	.069	.066	.084	.085
D	.065	.075	.081	.080
E	.068	.069	.079	.082
F	.072	.069	.076	.079
G	.067	.068	.077	.084
H	.066	.069	.081	.074
Average	.072	.071	.084	.086

Table 5

Analysis of Slags.

	Per Cent			
Heat	SiO_2	FeO	MgO	CaO
1	42.20	2.38	1.92	31.11
..	41.90	3.00	14.10	20.21
9 ..	44.24	2.90	1.38	31.85
10. ..	42.56	2.92	11.70	18.82
17.	42.86	3.94	1.67	35.00
18.	42.02	3.22	14.60	22.80

Table 6

Chemical Analysis of Heats 1 and 2 by Tap.

Tap	C	Si	Mn	P	S
	Per Cent				
Heat 1—Limestone					
A	3.58	2.02	0.54	0.28	0.100
B	3.55	2.05	0.59	0.27	0.090
C	3.48	2.05	0.60	0.33	0.089
D	3.37	2.00	0.63	0.34	0.084
E	3.38	1.98	0.61	0.35	0.086
F	3.38	1.96	0.60	0.32	0.086
G	3.33	1.90	0.71	0.31	0.082
H	3.38	1.90	0.58	0.30	0.078
Average	3.43	1.98	0.61	0.31	0.087
Heat 2—Dolomite					
A	3.60	1.96	0.53	0.32	0.112
B	3.50	2.05	0.59	0.29	0.092
C	3.43	2.06	0.62	0.33	0.089
D	3.31	2.02	0.61	0.29	0.090
E	3.31	1.97	0.61	0.31	0.087
F	3.35	1.96	0.62	0.33	0.086
G	3.31	1.86	0.64	0.31	0.087
H	3.26	1.87	0.61	0.30	0.087
Average	3.38	1.97	0.60	0.31	0.091

Table 3

Influence of Lime and Dolomite Fluxes on Sulphur Content of Cupola Irons. Cupola Slagged Intermittently.

Tap	Heats 1 2		Heats 3 4		Heats 5 6		Heats 7 8		Heats 9 10		Heats 11 12		Heats 13 14		Heats 15 16	
	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D
A	.100	.112	.093	.099	.105	.113	.101	.107	.107	.124	.124	.117	.119	.113	.115	.121
B	.090	.092	.085	.097	.093	.102	.088	.088	.101	.118	.106	.112	.115	.119	.112	.108
C	.089	.089	.092	.090	.091	.094	.089	.085	.091	.108	.098	.102	.124	.116	.109	.114
D	.084	.090	.087	.089	.085	.093	.087	.084	.093	.103	.089	.102	.116	.121	.108	.111
E	.086	.087	.082	.090	.079	.085	.081	.080	.093	.100	.090	.101	.113	.117	.109	.113
F	.086	.086	.078	.089	.083	.078	.079	.084	.094	.098	.096	.105	.110	.112	.112	.108
G	.082	.087	.079	.085	.082	.078	.080	.084	.089	.102	.091	.100	.114	.118	.110	.108
H	.078	.087	.079	.081	.073	.079	.076	.087	.093	.098	.100	.108	.114	.117	.107	.107
Average	.087	.091	.084	.090	.086	.090	.098	.100	.095	.106	.099	.106	.116	.117	.110	.111

Table 7

CHEMICAL ANALYSIS OF HEATS 3 AND 4 BY TAP.

	Heat 3—Limestone					Heat 4—Dolomite				
Tap	*C*	*Si*	*Mn*	*P*	*S*	*C*	*Si*	*Mn*	*P*	*S*
A	3.52	2.07	0.59	0.29	0.093	3.64	2.13	0.59	0.29	0.099
B	3.60	2.14	0.62	0.31	0.085	3.60	2.14	0.61	0.30	0.097
C	3.58	2.04	0.61	0.31	0.092	3.54	2.10	0.61	0.29	0.090
D	3.54	2.04	0.62	0.31	0.087	3.53	2.12	0.65	0.29	0.089
E	3.52	2.06	0.64	0.31	0.082	3.34	2.11	0.62	0.31	0.090
F	3.53	2.09	0.64	0.31	0.078	3.51	2.16	0.63	0.31	0.089
G	3.50	2.07	0.65	0.31	0.079	3.48	2.10	0.63	0.32	0.085
H	3.49	2.05	0.64	0.31	0.079	3.50	2.18	0.63	0.32	0.081
Average	3.53	2.07	0.63	0.31	0.084	3.54	2.13	0.62	0.30	0.090

Table 8

CHEMICAL ANALYSIS OF HEATS 5 AND 6 BY TAP.

	Heat 5—Limestone					Heat 6—Dolomite				
Tap	*C*	*Si*	*Mn*	*P*	*S*	*C*	*Si*	*Mn*	*P*	*S*
A	3.60	2.09	0.56	0.34	0.105	3.49	2.13	0.59	0.34	0.113
B	3.52	2.10	0.58	0.32	0.093	3.50	2.16	0.60	0.33	0.102
C	3.56	2.08	0.58	0.33	0.091	3.51	2.14	0.60	0.32	0.094
D	3.50	2.09	0.61	0.33	0.085	3.46	2.07	0.59	0.33	0.093
E	3.53	2.12	0.61	0.32	0.079	3.51	2.12	0.61	0.34	0.085
F	3.51	2.08	0.61	0.32	0.083	3.53	2.13	0.59	0.31	0.078
G	3.52	2.09	0.58	0.32	0.082	3.46	2.15	0.63	0.35	0.078
H	3.52	2.03	0.60	0.33	0.073	3.42	2.15	0.63	0.34	0.079
Average	3.53	2.09	0.59	0.33	0.086	3.48	2.13	0.61	0.33	0.090

Table 9

CHEMICAL ANALYSIS OF HEATS 7 AND 8 BY TAP.

	Heat 7—Limestone					Heat 8—Dolomite				
Tap	*C*	*Si*	*Mn*	*P*	*S*	*C*	*Si*	*Mn*	*P*	*S*
A	3.46	2.09	0.57	0.34	0.101	3.42	2.11	0.57	0.34	0.107
B	3.47	2.05	0.57	0.33	0.088	3.42	2.14	0.61	0.33	0.088
C	3.41	2.15	0.59	0.33	0.089	3.44	2.15	0.60	0.35	0.085
D	3.39	2.11	0.60	0.35	0.087	3.40	2.16	0.60	0.35	0.084
E	3.40	2.12	0.59	0.33	0.081	3.36	2.06	0.59	0.34	0.080
F	3.29	2.23	0.62	0.34	0.079	3.33	2.06	0.59	0.34	0.084
G	3.30	2.21	0.61	0.35	0.080	3.34	2.08	0.59	0.32	0.084
H	3.28	2.11	0.60	0.35	0.076	3.29	2.14	0.60	0.33	0.087
Average	3.38	2.13	0.59	0.34	0.098	3.38	2.11	0.59	0.34	0.100

Table 10

CHEMICAL ANALYSIS OF HEATS 9 AND 10 BY TAP.

	Heat 9—Limestone					Heat 10—Dolomite				
Tap	*C*	*Si*	*Mn*	*P*	*S*	*C*	*Si*	*Mn*	*P*	*S*
A	3.39	2.02	0.54	0.37	0.107	3.40	2.06	0.53	0.37	0.124
B	3.48	2.06	0.57	0.36	0.101	3.39	2.10	0.56	0.35	0.118
C	3.36	2.10	0.59	0.36	0.091	3.33	2.11	0.57	0.36	0.108
D	3.33	2.00	0.58	0.38	0.093	3.37	2.09	0.55	0.35	0.103
E	3.36	2.01	0.59	0.38	0.093	3.32	2.10	0.57	0.38	0.100
F	3.32	1.90	0.57	0.37	0.094	3.35	2.07	0.57	0.38	0.098
G	3.41	2.06	0.60	0.36	0.089	3.37	2.03	0.56	0.36	0.102
H	3.39	2.01	0.58	0.38	0.093	3.38	2.06	0.55	0.40	0.098
Average	3.38	2.02	0.58	0.37	0.095	3.37	2.08	0.57	0.37	0.106

Table 11

CHEMICAL ANALYSIS OF HEATS 11 AND 12 BY TAP.

	Heat 11—Limestone					Heat 12—Dolomite				
Tap	*C*	*Si*	*Mn*	*P*	*S*	*C*	*Si*	*Mn*	*P*	*S*
A	3.53	2.02	0.52	0.31	0.124	3.53	2.19	0.57	0.32	0.117
B	3.46	2.09	0.60	0.32	0.106	3.46	2.20	0.61	0.32	0.112
C	3.47	2.14	0.62	0.32	0.098	3.43	2.19	0.62	0.32	0.102
D	3.45	2.14	0.63	0.32	0.089	3.40	2.18	0.63	0.32	0.102
E	3.40	1.96	0.62	0.31	0.090	3.42	2.19	0.63	0.31	0.101
F	3.39	2.07	0.63	0.31	0.096	3.39	2.13	0.61	0.30	0.105
G	3.41	2.13	0.62	0.34	0.091	3.43	2.14	0.62	0.32	0.100
H	3.34	2.07	0.61	0.31	0.100	3.40	2.01	0.58	0.31	0.108
Average	3.43	2.08	0.61	0.32	0.099	3.43	2.15	0.61	0.32	0.106

second series. The figures are the average of two determinations. These data indicate that the limestone is not inferior to dolomite in desulphurizing ability. In those cases where an appreciable difference appears in the average sulphur content for the heat, the limestone heats have the lowest sulphur irons. Of the 64 pairs of irons of series one, 48 (75 per cent) show higher sulphurs in the dolomite heats.

A number of slags were analyzed for CaO, MgO, FeO, and SiO_2 contents. Results are presented in Table 5. The magnesia contents of the dolomite slags are in the range which should produce a slag of low viscosity relative to the plain lime slag. The data indicate slags within the composition limits recommended for good cupola practice.

Slag Analysis

The figure for iron oxide is for total iron reported as ferrous oxide. Slag samples were collected just before tap "E" in the case of those heats which were slagged intermittently. The slags as collected in a half-inch layer in an iron pot were dark green with brownish colored streaks.

No difference in the appearance of the lime slags as compared with the dolomite slags could be detected. All slags showed some tendency to wool at the slag hole.

No variation in the viscosity of the lime and dolomite slags was apparent as judged by the flow from the slag hole. Examination of cupola lining disclosed no correlation between lining condition and the type of flux used.

Tables 6 to 11 give the complete analysis of all heats from 1 to 12. The average values for all the taps of each heat are presented in Table 12. No effect of the fluxes on carbon, manganese, phosphorus and silicon contents can be established from these data, with the possible exception of a tendency for the silicon loss to run slightly higher in the heats where limestone was used.

Test bars were selected from corresponding taps of each pair of heats where the analysis of the two taps were in close agreement. Results, with the silicon and carbon contents of the irons, are in Table 13. Transverse strengths are the average of three 1.2-in. standard transverse bar results.

Table 12

AVERAGE CHEMICAL ANALYSIS BY HEAT.

Heat	Limestone C	Si	Mn	P	S	Heat	Dolomite C	Si	Mn	P	S
1	3.43	1.98	0.61	0.31	0.087	2	3.38	1.97	0.60	0.31	0.091
3	3.53	2.07	0.63	0.31	0.084	4	3.54	2.13	0.62	0.30	0.090
5	3.53	2.09	0.59	0.33	0.086	6	3.48	2.13	0.61	0.33	0.090
7	3.38	2.13	0.59	0.34	0.098	8	3.38	2.11	0.59	0.34	0.100
9	3.38	2.02	0.58	0.37	0.095	10	3.37	2.08	0.57	0.37	0.106
11	3.43	2.08	0.61	0.32	0.099	12	3.43	2.15	0.61	0.32	0.106

Table 13

SUMMARY OF RESULTS ON PHYSICAL TESTS BY TAP.

Iron	Limestone C	Si	Tensile Strength, psi.	Transverse Strength, psi.	Deflection, in.	BHN	Chill, in.	Iron	Dolomite C	Si	Tensile Strength, psi.	Transverse Strength, psi.	Deflection, in.	BHN	Chill, in.
1D	3.37	2.00	35,640	2,287	0.270	210	0.55	2D	3.31	2.02	35,040	2,403	0.280	207	0.50
1F	3.38	1.96	35,170	2,363	0.290	217	0.47	2F	3.35	1.96	36,470	2,454	0.302	211	0.50
3B	3.60	2.14	26,980	1,946	0.272	192	Defec.	4B	3.60	2.14	25,050	1,806	0.273	181	Defec.
5D	3.50	2.09	32,410	2,246	0.294	197	0.28	6D	3.46	2.07	31,400	2,222	0.300	199	0.28
5E	3.53	2.12	30,290	2,164	0.299	187	0.30	6E	3.51	2.12	32,150	2,231	0.279	195	0.33
7A	3.64	2.09	29,490	2,076	0.303	186	0.28	8A	3.42	2.11	32,150	2,199	0.271	192	0.32
7C	3.41	2.15	33,000	2,265	0.295	191	0.32	8C	3.44	2.15	32,830	2,228	0.269	194	0.28
7H	3.28	2.11	34,270	2,367	0.286	197	0.28	8H	3.29	2.14	33,400	2,331	0.282	196	0.32
9A	3.39	2.02	27,830	2,215	0.333	185	0.22	10A	3.40	2.06	32,840	2,377	0.267	195	0.22
9C	3.36	2.10	33,350	2,395	0.320	195	0.30	10C	3.33	2.11	36,290	2,552	0.318	202	0.30
9G	3.41	2.06	34,200	2,444	0.309	203	0.28	10G	3.37	2.03	34,700	2,532	0.303	210	0.25

The bars were poured in oil sand cores coated with a non-carbonaceous wash. Brinell readings were taken on sections from the transverse bars. Tensile specimens were machined from the transverse pieces. The tensile results are based on one bar. The chill test employed was a small wedge poured in a core sand mold.

Sections for examination under the microscope were prepared from the bars of Table 13. No relation between flux and the microstructure of the irons was found.

Discussion and Conclusions

The following conclusions apply when dolomite is substituted for limestone on a lb. for lb. basis in amounts which are recommended for good cupola practice, and which produce slags within the composition limits recommended in the literature for satisfactory operation of the cupola:

1. The substitution of dolomite for limestone in amounts of about 4 per cent of the metal charge results in no advantage as far as reduction of sulphur content of the iron is concerned. A total of 20 heats were run in pairs, one member of the pair under dolomite and the other under limestone. In those cases where an appreciable difference was found in the average sulphur content for the heat, the limestone heats had the lower sulphur irons.

2. The substitution of dolomite for limestone does not change the carbon, phosphorus or manganese contents of the iron. The possibility of a slightly greater silicon loss for the limestone heats is indicated.

3. The physical properties and the microstructures of the irons are not influenced by changing from limestone to dolomite.

4. The use of dolomite in place of limestone does not improve the operation of the cupola as far as slagging or lining attack is concerned.

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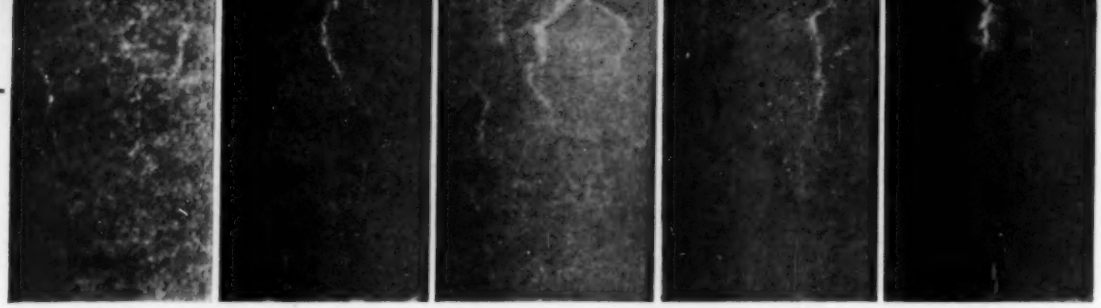

(1) (2) (3) (4) (5)

Table 1
PHYSICAL PROPERTIES OF UNBONDED BASIS SANDS

	Basis Sands				
Physical Properties	(1) *Ottawa Crude Wet (Y)*	(2) *Missouri Crude Wet (O)*	(3) *Missouri Crude Dry (O)*	(4) *Missouri Crude Dry (G)*	(5) *Missouri Crude Dry (M)*
Moisture, per cent	3.2	3.0	3.0	3.2	3.0
Green Permeability	280	190	190	110	140
Green Compression Strength, psi.	0.7	0.7	0.5	1.0	1.0
Required for 2-in. Cyl., grams	176	168	166	172	160
Required for 1⅛-in. Cyl., grams	53	48.2	51	51.5	48.7
Hot Strength at 2500° F., psi.	2.5	4	1	3.5	4
Hot Deformation at 2500° F., in./in.	0.0125	0.055	Very High	0.050	0.040
Total Expansion, 0.001 in./in.	0.015	0.01675	0.0148	0.01475	0.01475
Total Contraction, 0.001 in./in.	0.008	0.01525	0.0148 (3 min. 45 sec.)	0.01475 (7 min. 40 sec.)	0.01475 (10 min.)

MOLDING SAND PROPERTIES
at Elevated Temperatures

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IN THE foundry with which the authors are associated, five different basis sands are used in mold and core mixtures for the production of carbon steel railroad specialties such as locomotive beds, tender beds and frames, water bottoms, Pullman trucks, engine trucks, cradles and other auxiliaries. Certain heavy army ordnance castings in alloy steel are currently produced; also, heavy maritime castings. Weights of individual castings run from a few hundred lb. to 120,000 lb., with a majority of the castings weighing above 15,000 lb.

The use of a particular basis sand is dictated by economy, availability, method of molding, kind and size of casting and the sectional thicknesses involved. In a specific mold or core mixture no more than two basis sands are employed.

A well-equipped sand testing laboratory, operated 24 hrs. daily, checks and records a substantial number of the mold and core facing sand mixtures, and a lesser number of the mold and core backing sand mixtures which, together, account for the daily use of 1200 to 1400 tons of new and reclaimed sand. At the present time, all mold and core facing mixtures are made with new sand only.

The routine check and recording of mixtures includes moisture content, green and baked dry permeabilities, green and dry compression strength and tensile strength. A dilatometer is used principally for investigative purposes, although expansion, contraction, deformation, shock and hot strength determinations are made and periodically checked for each standard mold, core and backing sand mixture.

Since the dilatometer is a relatively new tool in foundry use (about 2½ years in this foundry)

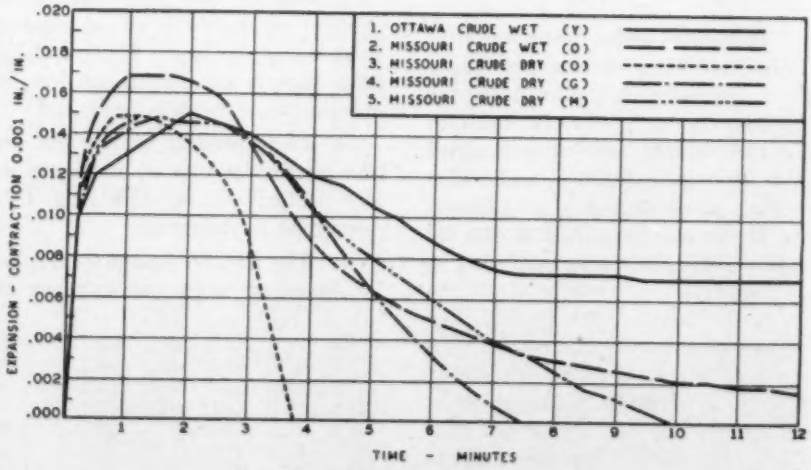


Fig. 1—Expansion-contraction curves for unbonded basis sands. These tests were made at a temperature of 2500° F.

and, since it opened up a new field of observation, the authors have chosen to employ it in exploring this new field rather than to confine its use to routine checks.

The results of the initial work with the dilatometer were compared with published data and, on this basis, a number of the sand mixtures used were found to be faulty in that spalling, shelling or cracking

• Physical properties of bonded and unbonded molding sands at elevated temperatures have been extensively investigated by the authors and are presented comparatively in tabular and graphic form. The paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Steel Division of A.F.A.

occurred under shock testing (introducing a specimen 2-in. long by 1⅛-in. diameter at room temperature to a 2500° F. atmosphere for a period of about 3 min.).

In the standard green sand mixture, one of the basis sands used is an Ottawa grade with an A.F.A. Fineness No. of 44 to 48 and a natural clay content of 2 to 3 per cent. Using this for experimentation, it was found that additions of bentonite and cereal to obtain a ratio of two parts bentonite to one part cereal resulted in a specimen having no visible defects from shock testing at 2500° F. for 3 min.

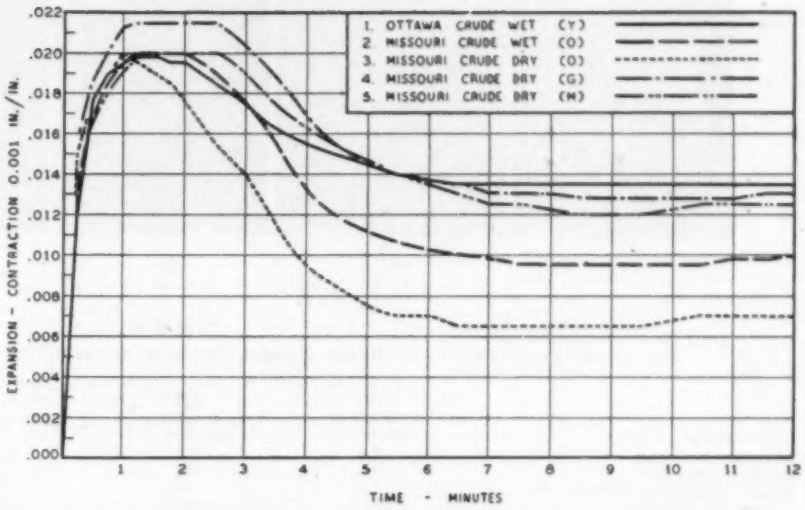


Fig. 2—Expansion-contraction curves showing effect of one per cent bentonite addition to basis sands. Test temperature—2500° F.

Changing only the basis sand to a crude Missouri grade with an A.F.A. Fineness No. of 50 to 54 and an A.F.A. clay content of 0.5 to 1.0 per cent, resulted in a specimen which, on shock testing, shelled and cracked badly. Altering the binder content to a ratio of three parts of bentonite to one of cereal eliminated the shelling on shock testing. A further adjustment in the binder ratio of four parts of bentonite to one of cereal produced a specimen which, on shock testing, did not shell, crack or show any visible defect as did other test specimens.

These results led to a broader investigation of all basis sands used. Selected samples of each were tested in a variety of ways with the results as shown in the following tables, graphs and photomicrographs (Tables 1-7 and Figs. 1-7).

Procedure

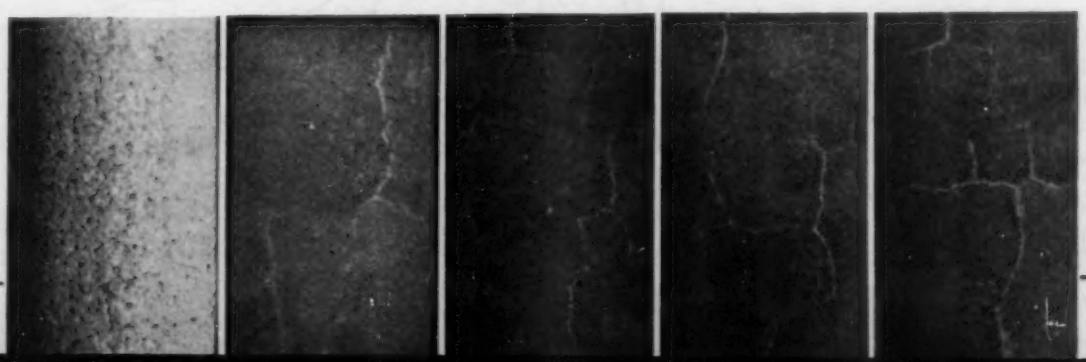
Since previous tests taken from numbers of cars arriving at the plant, particularly Missouri sands, disclosed variations in sand characteristics, the authors selected for the basis of this investigation a 1000-lb. sample from a single car, for each of the sands tested. The five samples of sand selected had been found

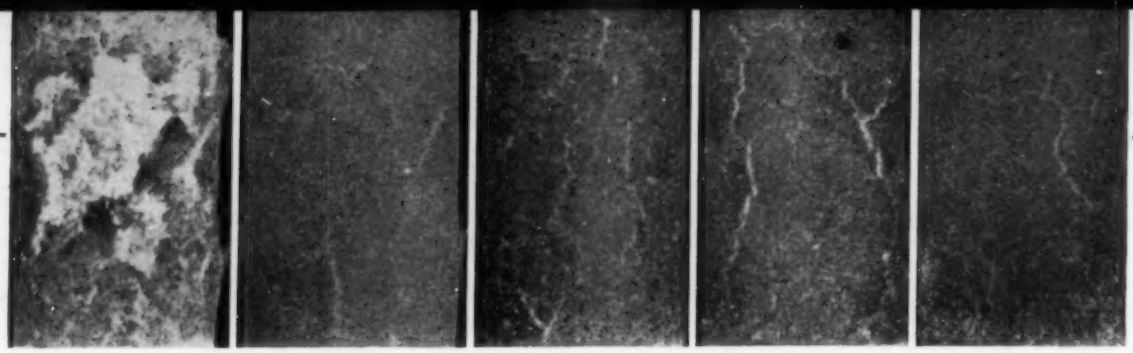
Table 2

PHYSICAL PROPERTIES OF BASIS SANDS BONDED WITH ONE PER CENT OF BENTONITE

	Basis Sands				
Properties	(1) *Ottawa Crude Wet (Y)*	(2) *Missouri Crude Wet (O)*	(3) *Missouri Crude Dry (O)*	(4) *Missouri Crude Dry (G)*	(5) *Missouri Crude Dry (M)*
Moisture, per cent	3.0	3.0	3.0	3.0	3.2
Green Permeability	210	180	190	100	120
Green Compression Strength, psi.	2.8	1.7	1.5	2.6	1.8
Increase, per cent	300.0	142.8	200.0	160.0	80.0
Required for 2-in. Cyl., grams	175	166	168	171	163
Required for 1⅛-in. Cyl., grams	53	51.6	51.6	52.5	50.6
Hot Strength at 2500° F., psi.	6	6	6	7	11-12
Hot Deformation at 2500° F., in./in.	0.020	Very High	Very High	Very High	0.035
Total Expansion, 0.001 in./in.	0.01975	0.020	0.020	0.0215	0.020
Total Contraction, 0.001 in./in.	0.00625	0.0105	0.0135	0.00875	0.008

(1) (2) (3) (4) (5)





(1) (2) (3) (4) (5)

Table 3

PHYSICAL PROPERTIES OF BASIS SANDS BONDED WITH ONE PER CENT OF CEREAL BINDER

	Basis Sands				
Properties	(1) *Ottawa Crude Wet (Y)*	(2) *Missouri Crude Wet (O)*	(3) *Missouri Crude Dry (O)*	(4) *Missouri Crude Dry (G)*	(5) *Missouri Crude Dry (M)*
Moisture, per cent	3.0	3.0	3.4	3.0	3.4
Green Permeability	190	150	150	120	110
Green Compression Strength, psi	2.5	1.6	1.6	2.1	1.6
Increase, per cent	257.0	128.6	220.0	110.0	60.0
Required for 2-in. Cyl., grams	175	169	170	172	167
Required for 1⅛-in. Cyl., grams	53	50.9	52	51.0	49.8
Hot Strength at 2500° F., psi.	1½	3	2	3½-4	5½-6
Hot Deformation at 2500° F., in./in.	0.010	0.0425	0.030	0.055	0.055
Total Expansion, 0.001 in./in.	0.012	0.01525	0.0135	0.017	0.01625
Total Contraction, 0.001 in./in.	0.008	0.01525 (8 min. 15 sec.)	0.0135 (3 min. 57 sec.)	0.017 (7 min. 30 sec.)	0.01075

to give a representative average shock test result for that sand.

All green sand testing was done in conformity with the standard American Foundrymen's Association testing procedure.

Unbonded basis sands were not milled in the laboratory muller type mill. Tempering to desired moisture was done by hand mixing in a large mixing bowl. This was to insure the minimum amount of segregation and loss of clay substance in unbonded sands. Basis sands, to which binders and other mixture ingredients were added, were mixed one min. dry in a muller type laboratory mill, after which the predetermined amount of water was added and the mixture mulled 4 min.

Dilatometer test specimens were dried for one hour at 200 to 220° F. and stored in desiccators until time of testing.

Deformation Tests

Shock tests were made by exposing test specimens at a temperature of 2500° F. for 3 min.

Hot strength and deformation tests were made by determining the compression strength in psi. after 12 min. soaking at 2500° F.

Expansion and contraction values were obtained at a temperature of 2500° F., recording them at 15-sec. intervals for the first 2 min. and every 30 sec. thereafter for a total testing time of 12 min. Contraction values were not recorded after test specimens had contracted to their original length in less than the 12 min. testing time.

The data as presented are an informative story of the physical characteristics of the five unbonded basis sands and the resulting change in physical characteristics when bentonite, cereal binder and other mixture ingredients were introduced to these sands. Values given were obtained by repeated tests, and the authors now accept them as giving a definite pattern of results, indicative of what one would expect, and (when applied) applicable to other mixture compositions in which these five sands may become a part. The discussion of data will be confined mostly to clarification of those values which the authors found did not conform to previously accepted ideas.

Cooling Methods

A brief consideration of the cooling methods employed by the Missouri sand producers in producing the three dry sands is important, for it has been found that they may greatly change the physical characteristics of a sand. Missouri crude dry sands *(O)* and *(M)* are cooled using coils of cool water and forced draft. Missouri crude dry sand *(G)* is cooled under normal atmospheric conditions and time.

Crude wet sand *(O)* and crude dry sand *(O)* are mined not more than 1000 ft. apart. An investigation of the two sands has shown

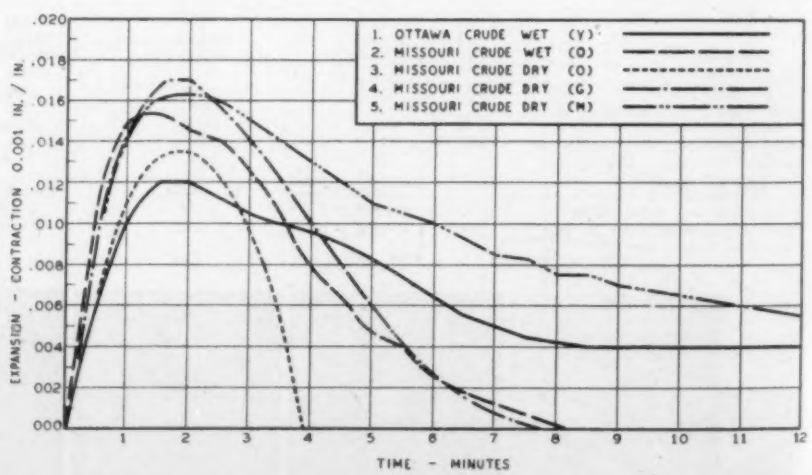


Fig. 3—Expansion-contraction curves showing effect of one per cent cereal binder on basis sands. Test Temperature—2500° F.

that these sands give reasonably identical test results throughout the various production steps, up to the operation where forced draft is employed to cool the sand.

When crude dry sand *(O)* was permitted to cool under atmospheric conditions, the sand test characteristics did not change; however, a change in test results did occur when the sand was cooled by forced draft. The use of forced draft has resulted in the removal of fine natural clay substance and other fine particles, producing a cleaner sand, which is not necessarily a desirable condition from the authors' point of view, as a study of the data will show.

A.F.A. Fineness Nos.

The A.F.A. Fineness Nos. and permeability values of Missouri crude dry sand *(O)* and *(M)* are not in the proper relationship with the three other sands comprising this report. It has been found that a greater amount of bonding material is required to give proper working strength, and that the bentonite to cereal ratio also must be increased to insure suitable specimen characteristics at elevated temperatures.

A moisture content of 3.0 to 4.0 per cent in tempered molding sand has proved to give the best casting results at this plant. For this reason it was decided to study basis sands and sand mixture characteristics within this same moisture range. However, as data were accumulated it was found that a large majority of tests were being made with sands and sand mixtures in a narrower moisture range, 3.0 to 3.6 per cent. It was then decided that for the entire study the moisture range be 3.0 to 3.6 per cent, and for indiviudal groups to have even less variation. This should practically eliminate moisture as a variable in influencing any sand mixture characteristic.

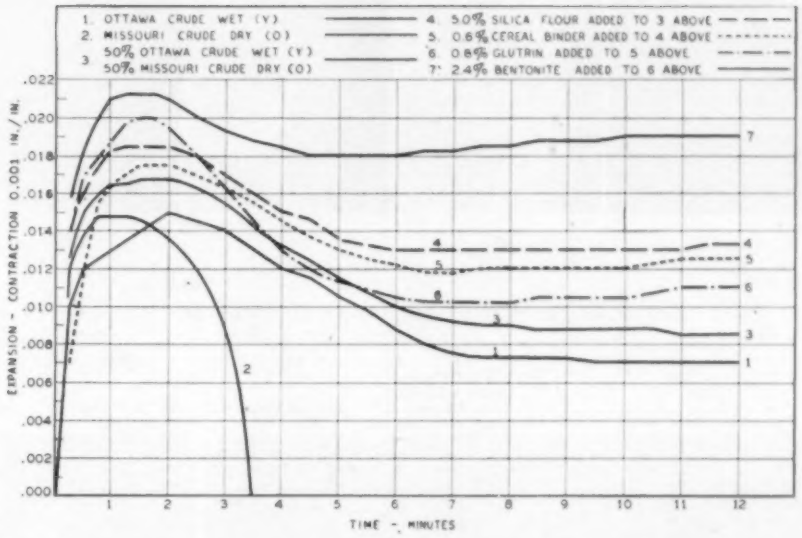

1. OTTAWA CRUDE WET (Y)
2. MISSOURI CRUDE DRY (O)
3. 50% OTTAWA CRUDE WET (Y) 50% MISSOURI CRUDE DRY (O)
4. 5.0% SILICA FLOUR ADDED TO 3 ABOVE
5. 0.6% CEREAL BINDER ADDED TO 4 ABOVE
6. 0.8% GLUTRIN ADDED TO 5 ABOVE
7. 2.4% BENTONITE ADDED TO 6 ABOVE
EXPANSION - CONTRACTION 0.001 IN./IN.
TIME - MINUTES

Fig. 4—Expansion-contraction curves showing influence of various additions on basis sands. Additions introduced in consecutive steps. Test temperature—2500° F.

From the screen analysis and green permeability values for unbonded basis sands, Ottawa crude wet sand *(Y)*, Missouri crude wet sand *(O)* and Missouri crude dry sand *(G)*, we find a permeability and fineness number relation which one would expect; that is, having decreasing permeability values as the fineness number of the sand increases. Missouri crude dry sands *(O)* and *(M)* are contrary in this respect. Crude dry sand *(M)* has the highest fineness number, but the permeability is always greater than the permeability of dry sand *(G)* which has a lower fineness number.

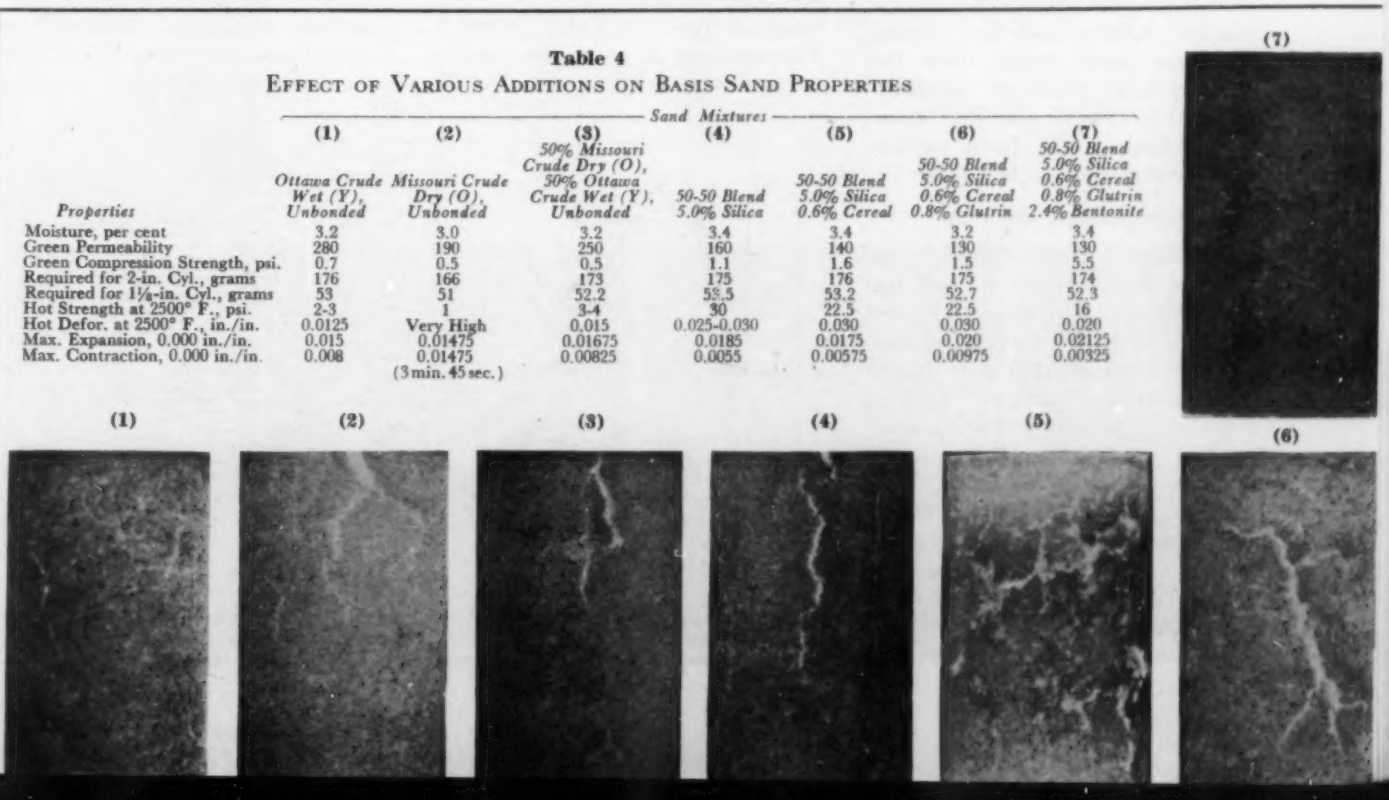
The reason for this irregularity in permeability values is due to the elimination of clay substance in cooling of sand after drying. This condition was described in the foregoing paragraphs of this paper.

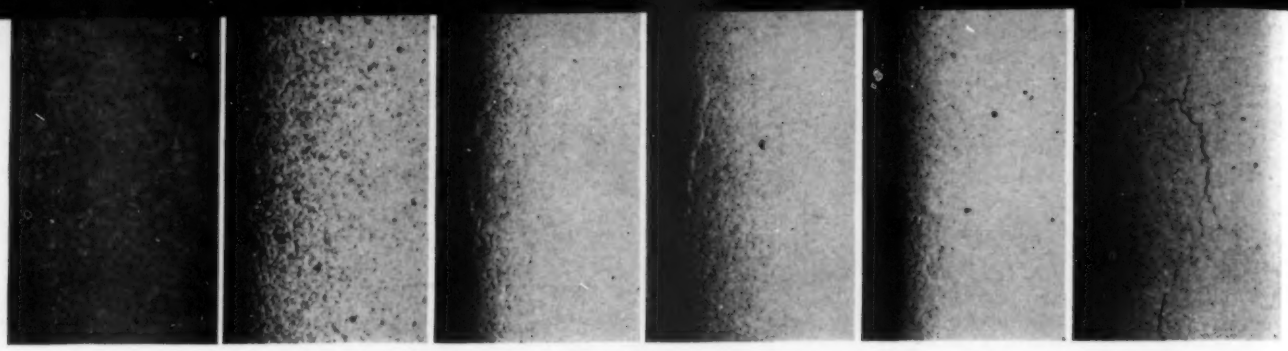
The green compression strength as

Table 4

EFFECT OF VARIOUS ADDITIONS ON BASIS SAND PROPERTIES

	Sand Mixtures						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Properties	*Ottawa Crude Wet (Y), Unbonded*	*Missouri Crude Dry (O), Unbonded*	*50% Missouri Crude Dry (O), 50% Ottawa Crude Wet (Y), Unbonded*	*50-50 Blend 5.0% Silica*	*50-50 Blend 5.0% Silica 0.6% Cereal*	*50-50 Blend 5.0% Silica 0.6% Cereal 0.8% Glutrin*	*50-50 Blend 5.0% Silica 0.6% Cereal 0.8% Glutrin 2.4% Bentonite*
Moisture, per cent	3.2	3.0	3.2	3.4	3.4	3.2	3.4
Green Permeability	280	190	250	160	140	130	130
Green Compression Strength, psi.	0.7	0.5	0.5	1.1	1.6	1.5	5.5
Required for 2-in. Cyl., grams	176	166	173	175	176	175	174
Required for 1⅛-in. Cyl., grams	53	51	52.2	53.5	53.2	52.7	52.3
Hot Strength at 2500° F., psi.	2-3	1	3-4	30	22.5	22.5	16
Hot Defor. at 2500° F., in./in.	0.0125	Very High	0.015	0.025-0.030	0.030	0.030	0.020
Max. Expansion, 0.000 in./in.	0.015	0.01475	0.01675	0.0185	0.0175	0.020	0.02125
Max. Contraction, 0.000 in./in.	0.008	0.01475 (3 min. 45 sec.)	0.00825	0.0055	0.00575	0.00975	0.00325





(1) (2) (3) (4) (5) (6)

Table 5

PHYSICAL PROPERTIES OF IDENTICAL MIXTURE INGREDIENTS WITH DIFFERENT BASIS SANDS

	Sand Mixtures					
	(1)	(2)	(3)	(4)	(5)	(6)
Properties	*50% Ottawa Crude Wet (Y) 50% Missouri Crude Dry (O) 5.0% Silica Flour 0.6% Cereal Binder 0.8% Glutrin 2.4% Bentonite*	*Ottawa Crude Wet (Y) 5.0% Silica Flour 0.6% Cereal Binder 0.8% Glutrin 2.4% Bentonite*	*Missouri Crude Wet (O) 5.0% Silica Flour 0.6% Cereal Binder 0.8% Glutrin 2.4% Bentonite*	*Missouri Crude Dry (O) 5.0% Silica Flour 0.6% Cereal Binder 0.8% Glutrin 2.4% Bentonite*	*Missouri Crude Dry (G) 5.0% Silica Flour 0.6% Cereal Binder 0.8% Glutrin 2.4% Bentonite*	*Missouri Crude Dry (M) 5.0% Silica Flour 0.6% Cereal Binder 0.8% Glutrin 2.4% Bentonite*
Moisture, per cent	3.4	3.4	3.6	3.6	3.6	3.6
Green Permeability	130	180	120	130	100	90
Green Compression Strength, psi.	5.5	6.3	5.0	4.0	5.3	5.1
Required for 2-in. Cyl., grams	174	175	170	171	174	165
Required for 1⅛-in. Cyl., grams	52.3	52.5	51.5	51.6	52.7	49.5
Hot Strength at 2500° F., psi.	16	8-9	15	13-14	10-11	15
Hot Deformation at 2500° F., in./in.	0.020	0.020	0.030	0.020	0.030	0.0275
Total Expansion, 0.001 in./in.	0.02125	0.02175	0.02225	0.0215	0.0215	0.021
Total Contraction, 0.001 in./in.	0.00325	0.0055	0.00875	0.0065	0.007	0.0055

found in unbonded basis sands was obtained from the natural clay bond present in the sand and the shape of sand grains. Natural clay bond in Ottawa crude wet sand *(Y)* is the contributing factor in producing green compression strength.

The Missouri sands are low in natural clay bond, and the green compression strength must be obtained from the predominating subangular shaped grains, which on being rammed become interlocking.

On examination of the photomicrographs, one can readily see the rounded surfaces and clay coating of Ottawa sand grains, while the Missouri sand grains are predominantly clear crystals with little stain. Sharp edges on the grain surfaces are also very noticeable (Table 7).

Green Compression Strength

Referring to Table 6, mention is made of the fact that washed and unbonded test specimens collapsed before testing. To further substantiate the previous statements regarding natural clay bond and shape of grain as contributing to green compression strength, the following observations made while collecting data for Table 6 should be related.

Test specimens of washed and unbonded crude Ottawa sand *(Y)* with 3 per cent moisture content would fall apart when stripped from the cylinder in which the specimen was rammed, the sand grains ranging from round to subangular. Rammed specimens of washed and unbonded Missouri sand when stripped from the cylinder would stand until drying started. This was only possible due to interlocking subangular shaped grains. The green compression strength could not be obtained due to the fact that the specimens fell apart when taken from the cylinder.

The green compression strength resulting from the addition of one per cent of bentonite or cereal binder is shown in Tables 2 and 3. This increase in green compression strength may be shown also as the percentage of strength increase.

Grams of Sand Required for 2x2-In. and 1⅛x2-In. Test Specimens

It is interesting to note that the amount of sand required to produce proper size test specimens was less when the basis sand was a Missouri sand. Also, there was considerable variation in the density relation between 2 in. and 1⅛ in. diameter test specimens. Through the entire investigation, which consisted of numerous confirming tests, it was found that the number of grams required to produce proper specimen size was uniformly consistent with Ottawa sand as the basis sand. This was not true with Missouri sands.

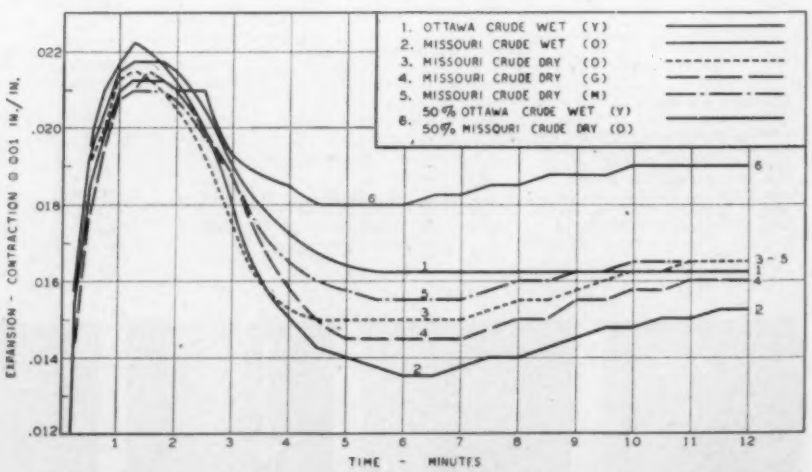

1. OTTAWA CRUDE WET (Y)
2. MISSOURI CRUDE WET (O)
3. MISSOURI CRUDE DRY (O)
4. MISSOURI CRUDE DRY (G)
5. MISSOURI CRUDE DRY (M)
6. 50% OTTAWA CRUDE WET (Y) 50% MISSOURI CRUDE DRY (O)
EXPANSION - CONTRACTION @ .001 IN./IN.
.022
.020
.018
.016
.014
.012
1 2 3 4 5 6 7 8 9 10 11 12
TIME - MINUTES

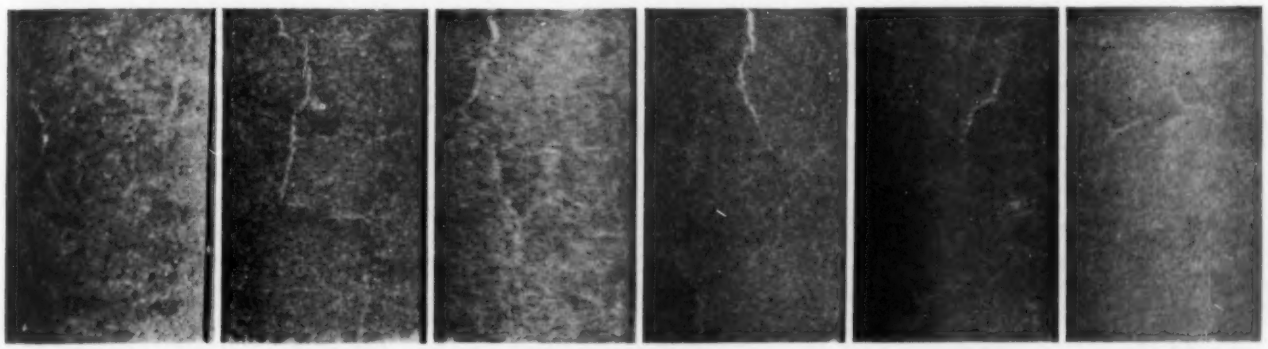
Fig. 5—Expansion-contraction curves showing effect of identical mixture additions with different basis sands. Additions are: Silica flour—5.0 per cent, cereal binder—0.6 per cent, glutrin—0.8 per cent, bentonite—2.4 per cent. Test temperature—2500° F.

Table 6

PHYSICAL PROPERTIES OF CRUDE BASIS SANDS AND OF WASHED BASIS SANDS REBONDED WITH 0.5% AND 1.0% BENTONITE

	Sand Mixtures					
	(1)	(2)	(3)	(4)	(5)	(6)
Properties	*Ottawa Crude Wet Sand (Y)*	*Ottawa Crude Washed Sand (Y), Rebonded 0.5% Bentonite*	*Ottawa Crude Washed Sand (Y), Rebonded 1.0% Bentonite*	*Missouri Crude Wet Sand (O)*	*Missouri Crude Washed Sand (O), Rebonded 0.5% Bentonite*	*Missouri Crude Washed Sand (O), Rebonded 1.0% Bentonite*
Moisture, per cent	3.2	3.2	3.0	3.0	3.2	3.0
Green Permeability	280	260	250	190	190	180
Green Compression Strength, psi.	0.7	0.8	1.3	0.7	0.8	1.6
Required for 2-in. Cyl., grams	176	172	170	168	167	164
Required for 1½-in. Cyl., grams	53	51.1	51.0	48.2	50	49.5
Hot Strength at 2500° F., psi.	2-3	2	2	4	2-3	2-3
Hot Deformation at 2500° F., in./in.	0.0125	0.0125	0.0135	0.055	0.0075	0.0175
Maximum Expansion, 0.001 in./in.	0.015	0.0175	0.018	0.01675	0.01825	0.01975
Maximum Contraction, 0.001 in./in.	0.0085	0.00425	0.005	0.01525	0.0055	0.00625

NOTE: Washed and unbonded test specimens collapse before tested.



(1) (2) (3) (4) (5) (6)

(1)

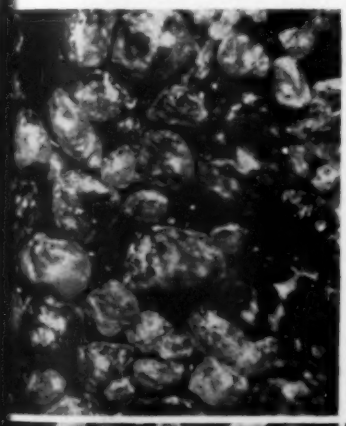
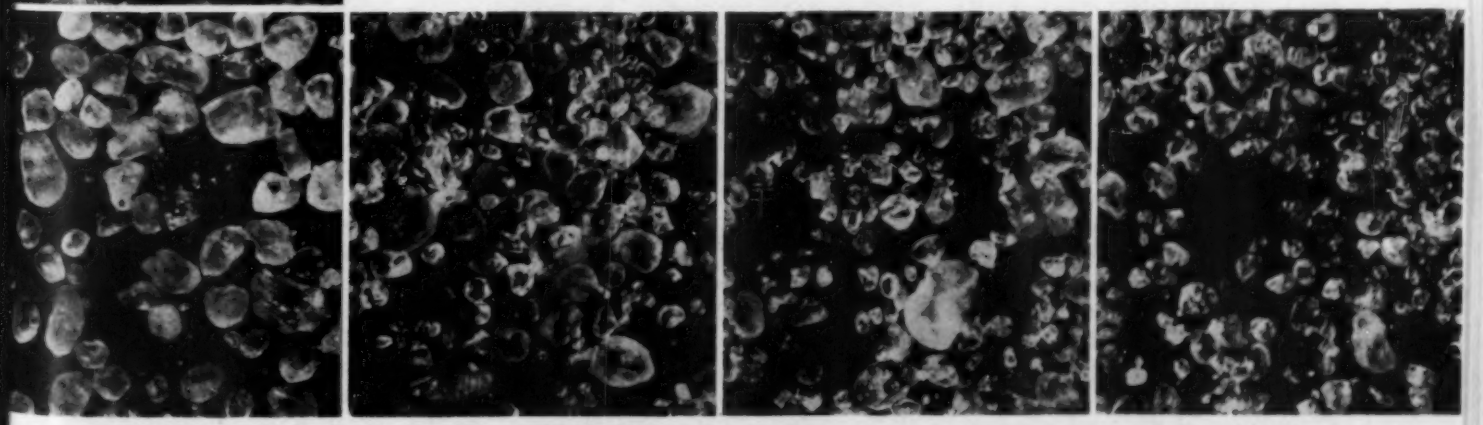


Table 7

SCREEN ANALYSIS OF BASIS SANDS

	Retained on Screen, per cent				
	(1)	(2)	(3)	(4)	(5)
Screen No.	*Ottawa Crude Wet Sand (Y)*	*Missouri Crude Wet Sand (O)*	*Missouri Crude Dry Sand (O)*	*Missouri Crude Dry Sand (G)*	*Missouri Crude Dry Sand (M)*
20	0	0	0	0.4	0
30	7.0	1.0	0.2	1.0	0.4
40	37.3	12.3	5.2	5.2	3.0
50	29.6	46.3	28.8	14.6	10.0
70	14.2	26.6	33.6	25.8	26.8
100	7.3	9.3	20.6	35.2	37.4
140	2.1	3.0	8.0	14.8	16.4
200	1.2	0.5	2.8	2.6	4.2
270	0.2	0.5	0.6	0.4	1.2
Pan	1.1	0.5	0.6	0.4	0.8
A.F.A. Fineness No.	44.1	48.3	58.4	65.2	71



(2) (3) (4) (5)

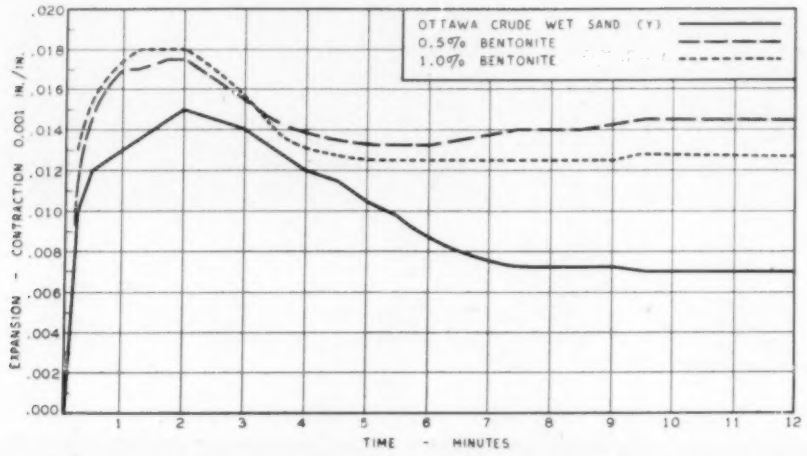


Fig. 6—Expansion-contraction curves of Ottawa crude wet sand (Y) and washed Ottawa crude sand (Y) rebonded with 0.5 per cent and 1.0 per cent of bentonite. Unbonded washed sand test specimens collapse on drying. Test temperature—2500° F.

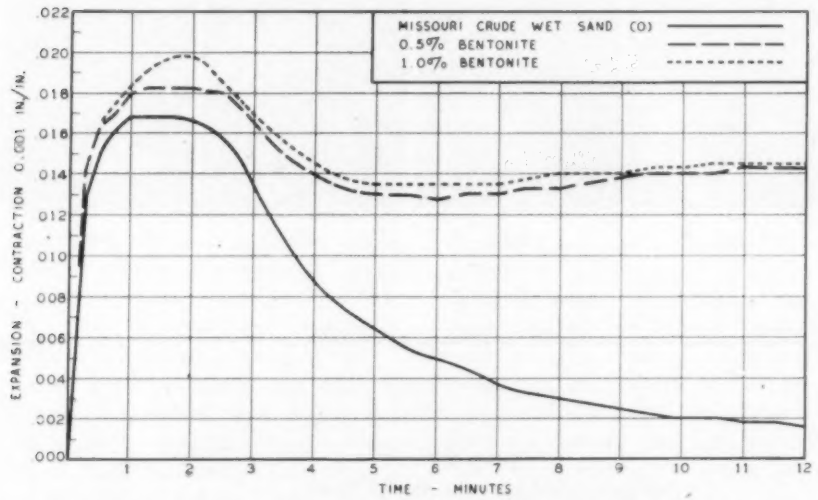


Fig. 7—Expansion-contraction curves of Missouri crude wet sand (O) and washed Missouri crude wet sand (O) rebonded with 0.5 per cent and 1.0 per cent of bentonite. Unbonded washed sand test specimens collapse on drying. Test temperature—2500° F.

The shape of the sand grains and their distribution is a contributing cause for this variation. The photomicrographs of the five basis sands (Table 7) show that the Missouri sands are subangular to angular, with many angular or elongated grains with sharp edges predominating. This angularity of grain shapes greatly retards the flowability or ramability of the sand.

Shape of Grains

The Ottawa sand grains, as the picture shows, are round to subangular, with no sharp edges on the grains, a factor necessary for high flowability. The absence of fine material in a basis sand may also affect the number of grams of sand required for proper size test specimens.

Comparison of the total influence that bentonite and cereal binder have on the hot strength of unbonded basis sands cannot be determined from the data. Unbonded basis sands were tempered by hand. To measure the total influence that these binders have on the basis sands, it would have been necessary to mull each of the unbonded sands in the laboratory mill for the same period of time that the sand mixtures were mixed and tempered. Mulling brings about a certain amount of sand grain breakdown, introducing a slight silica flour effect, which will increase the hot strength. With this exception the data do show that bentonite will increase hot strength, while cereal binder will reduce it.

The accuracy of the readings in this test is doubtful, in the opinion of the writers. That is why, on several occasions, when the values were more than 0.055 in./in., a written description as "very high" was used instead of numerical values.

Total Expansion and Total Contraction at 2500° F.

The total influence that additions of bentonite and cereal have on the expansion and contraction characteristics of basis sands cannot be determined from the data. Pioneers in sand testing at elevated temperatures early discovered that cereal binders decreased the rate and amount of expansion and increased the rate of collapse.

Comparing the dilation curves of Figs. 1 and 3, we find that the rate of expansion was retarded, as one would expect. However, not in every case was the total expansion reduced; neither was the total contraction or rate of collapsibility increased. Ottawa crude wet sand *(Y)* and Missouri crude wet sand *(O)* follow the pattern that one would expect. The Missouri crude dry sands *(G)*, *(M)* and *(O)* have not followed this pattern completely.

As previously stated, when discussing hot strength characteristics, the same influence that was brought about by mulling in mixing and tempering of basis sands to which binders or mixture ingredients were added, also affects the expansion and contraction characteristics.

As an added thought, segregation of sand grains, permitting an accumulation of more than average amount of "fines" for that particular basis sand, also may have the same influence on sand characteristics. These influences may be small and not noticeable in green or dry sand testing, but their influence is very noticeable in testing at elevated temperatures.

Conclusions

The data presented indicate that similar sand mixture bonding ingredients, of like proportions and used with different basis sands, are apt to produce widely different results at elevated temperatures.

The sand mixtures productive of the best elevated temperature shock test results and the cleanest casting had high expansion-low contraction characteristics.

The use of bentonite reduced contraction in all of the sand mixtures tested; it likewise contributed most to the reduction or elimination of

shelling, spalling and cracking in the sand mixtures tested.

Some basis sands require larger amounts of bentonite than others to produce equal results.

Missouri sands with bentonite-to-cereal ratios capable of producing best elevated temperature test results had relatively low flowability.

The influence of any mixture ingredient may vary with the kinds of basis sands used.

Laboratory observations in elevated temperature testing were found to reasonably parallel casting results. The use of sand mixtures which showed poorly under laboratory test always resulted in the castings having one or a number of the defects attributable to molding sand, and usually to the degree observed in laboratory tests of the sand mixtures at elevated temperatures.

Room temperature tests are of chief importance in the control of molding sand requirements up to the time of pouring. Tests at elevated temperatures are indicators of occurrences when metal enters and fills the mold.

The best casting results obtain from a sand mixture with proportions of bonding materials adjusted to suit the characteristics of the basis sand used. Under varying conditions and requirements of casting production, the selection of different basis sands may be advisable.

Welding Methods for GRAY IRON CASTINGS

By L. F. Granger,
The Linde Air Products Co., New York

• Two methods of welding are available to the gray iron foundryman—fusion welding and bronze welding. Joint preparation and cooling procedures are common to both methods. Each method has its advantages for particular applications, the choice of method depending upon proper evaluation of the various factors involved—chemical composition of the cast iron—service for which the part is intended—size of the part—subsequent finishing operations—cost of the welding operation.

WELDING of gray iron castings is not a new operation to the foundryman; this process has been used for more than 25 years in the gray iron foundry, for filling blowholes and building up undersized areas, and for the repair of castings broken in handling (Figs. 1 and 2). In fact, many large foundries have set up welding departments especially for doing this work.

In some instances the welding process is used for remodeling large, expensive castings when, as a result of changes in design, it is necessary to add members to the casting or to build up certain sections to provide additional strength.

Two Methods Available

The welding of cast iron is by no means confined to the foundry. In fact, this process is used throughout industry for repair and maintenance work. As practiced in the iron foundry, however, cast iron welding is done with a cast iron rod that will give a weld of about the same composition as the parent metal, and for this reason the foundryman may lose sight of the fact that two methods for welding cast iron are available, namely, the fusion method and the bronze method.

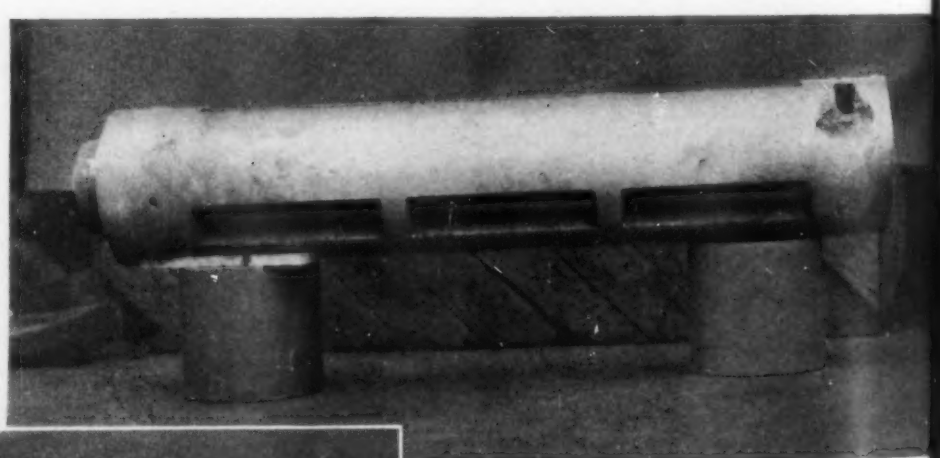
This paper will describe these methods briefly and explain the factors determining which method should be selected for a particular application. No attempt will be made to go into the details of the procedure for either method.

In the fusion welding method, a weld is made by melting the edges of cast iron pieces and filling the "V" with additional molten metal from a cast iron welding rod. Foundrymen are familiar with this method since it is used for depositing molten metal from a cast iron rod in a blowhole or other casting opening.

Bronze welding is a method of welding ferrous and non-ferrous metals with a bronze rod, rather than with a rod of the same composition as the parent metal. When cast iron is bronze welded, the base metal never actually is melted (Fig. 3). It is merely brought to a temperature high enough to cause the bronze to flow onto the surface of the base metal and bond with it.

This paper will not attempt to tell how each of these welding methods should be applied, but a brief outline of the procedures involved will serve to show the differences between the two methods.

An outline of the steps in the procedures for each method is identical, namely, joint preparation, preheating, welding, and cooling. The two methods differ markedly, how-



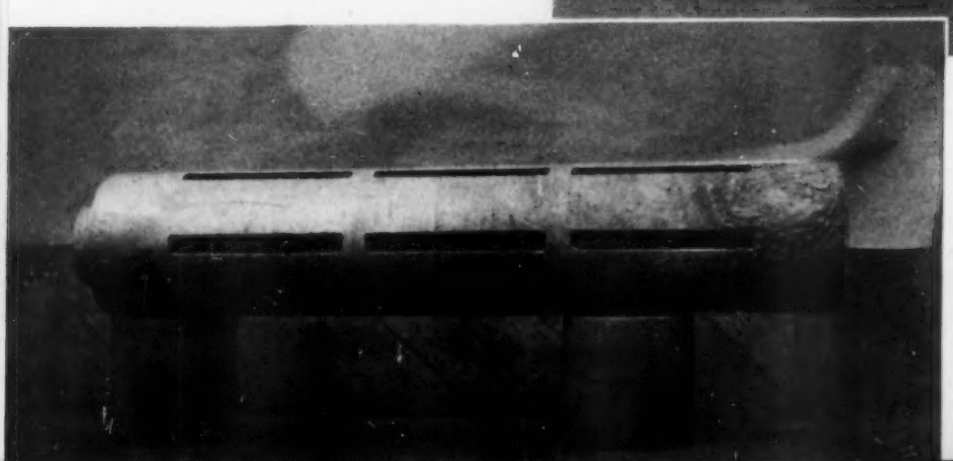


Fig. 1—(Above) Sink hole, 3-in. deep, in 8x40 in. corliss engine valve casting. Fig. 2—(Left) Defect was built up with 3¼ lb. of cast iron rod. After machining, the casting will be as good as new.

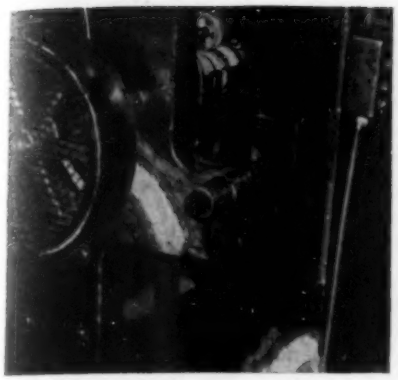


Fig. 3—When the cast iron frame of this paper cutoff machine was broken by an industrial truck, it was repaired in place by bronze welding.

ever, as regards preheating and welding. The differences in preheating requirements are a direct result of the differences in welding methods, which will therefore be repeated.

In the welding of cast iron with a cast iron rod, which is a true fusion method, the prepared edges of the parts to be joined must be heated to the melting temperature, and molten metal from the rod is then deposited in the "V" while its edges are in a molten condition.

In contrast to this, the base metal is not melted in bronze welding, but is merely brought to a temperature of between 1600 and 1700° F., or well below the melting point of cast iron. At this temperature, the bronze from the welding rod bonds with the surface of the base metal, forming a strong, ductile joining.

Considerably more heat is required to bring the edges of a break in an iron casting to the molten state (2050 to 2200° F.) required for fusion welding. Highly localized heat in areas not free to expand and contract is quite likely to produce excessive stresses in the work. For this reason, the general rule for fusion welding cast iron is that the entire casting should be preheated (Fig. 4) to a faint red (900 to 1050° F.) before welding. This prevents localized expansion and contraction stresses that might otherwise be sufficient to distort or crack the relatively brittle metal.

When a cast iron part is to be bronze welded, the casting should only be preheated to a black heat (800 to 900° F.) and often only in the vicinity of the break. The reason that local preheating is sufficient is that expansion and contraction stresses are greatly reduced because of the lower temperatures used in bronze welding, and because of the greater ductility of the weld metal.

Procedures Common to Both Methods

Whether a part is to be bronze welded or fusion welded, the joint preparation is usually the same (Fig. 5). The edges to be welded are beveled to form a 90° "V," with a hammer and cold chisel or on a grinding wheel. Both methods employ specially prepared fluxes to aid in controlling oxides formed during the welding operation.

The cooling procedure is likewise the same for both methods. The important factor is to protect the welded part from drafts during the cooling process; this is usually done by burying small parts in dry sand, slaked lime, dry asbestos cement or some other insulating medium, or by covering large parts with asbestos paper.

Fig. 4—Simple preheating furnaces for cast iron parts can be made from fire brick. The part should be supported on bricks above the bed of charcoal to assure uniform heating.

The choice between these two welding methods for a particular job depends on the chemistry of the cast iron to be welded, the service for which the part is intended, and the evaluation of other factors that influence the cost of doing the work and the results expected (Fig. 6). A listing of the advantages of each method will serve to show the factors in the selection of a method.

Fig. 5—This cast iron cylinder for a hoisting engine in a coal mine, of 16-in. diameter and 1-in. thickness, froze and cracked in cold weather. Sixteen pounds of bronze rod were used in repairing it.

Advantages of Fusion Welding

For all practical purposes, fusion welding is a recasting of the part being welded. The weld metal has the same color, the same composition, and the same structure as the parent metal (Fig. 7). The machining characteristics of a fusion weld are the same as those of the original cast iron throughout the weld zone.

Cast iron welding rod is considerably lower in cost than bronze welding rod. Absolute cleanliness of the surface to be welded is not as

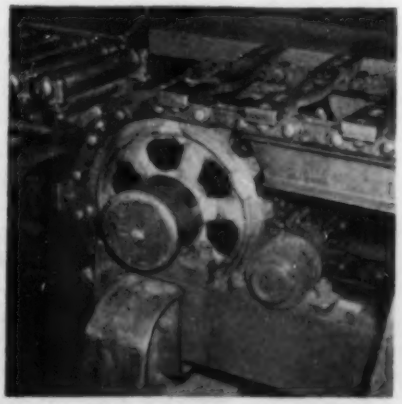


Fig. 6—Cast iron sprocket on the conveyor for a paper rewinder was broken into several pieces when the slats hung up. It was quickly repaired by bronze welding.

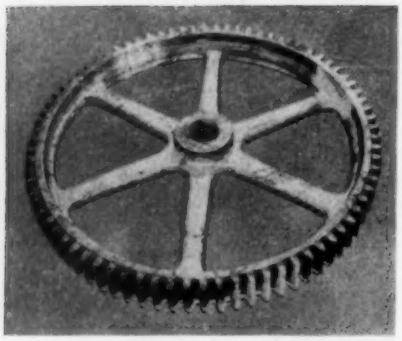


Fig. 7—The 4½-ft. bull gear for a veneer lathe was repaired by a combination of fusion welding and bronze welding. Two teeth at the 2 o'clock position were rebuilt with cast iron rod; the crack at the 11 o'clock position was bronze welded.

essential in fusion welding as it is in bronze welding.

The preheating and postheating of the entire part relieves locked-up stresses throughout, and often leaves the casting in better than original condition.

As has been brought out before, local preheating is usually sufficient for bronze welding. This advantage frequently makes it possible to make a repair in place by bronze welding, whereas it would be necessary to dismantle the machinery in order to make the same repair by fusion welding (Figs. 8 and 9).

The fact that bronze welding requires less heat than fusion welding naturally increases the speed of the joining, which, in turn, results in a decrease in time and gas consumption for a given job. Savings in time and gas offset somewhat the higher cost of the bronze rod.

The use of less heat also has other advantages, such as saving in the time required for the part to cool and less distortion of the part during the welding operation. Heat-treated surfaces are usually unaffected by the low temperature at which the bronze is deposited. The relatively high ductility of bronze weld metal permits of a slow yielding under reasonably low stresses, even at ordinary temperature, which acts to take up any slight readjustment in stresses during service.

The ease with which the welding operation can be performed is of little importance in choosing between the two methods since a skilled operator can handle either method with equal ease. In actual practice the welding operator may simply choose one method or the other according to his familiarity with it, without considering other factors.

Likewise the matter of strength need not be considered when the parts are to operate at service temperatures of under 500° F., since both methods produce welds as strong or stronger than the parent metal. Bronze loses strength at temperatures much above 500° F., and is therefore not feasible for parts which are to be raised subsequently to higher temperatures, either in service or during treatment (Figs. 10 and 11).

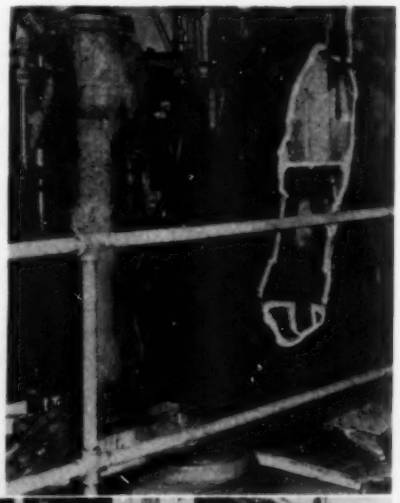
Entirely apart from the relative advantages of the two methods, one method or the other may be preferable for the job at hand because of the nature of the part or its intended use. For example, malleablized castings should always be bronze welded, and such white iron castings as might have to be reclaimed before heat treatment for conversion to malleable iron should always be fusion welded.

Also, fusion welding is the only satisfactory method of repairing "poisoned" castings such as machine parts that have become oil soaked in service, or castings that have been exposed to heat, such as boiler sections and grate bars (Fig. 12).

Fusion welding is naturally the preferred method for reclaiming defective gray iron castings in the foundry, since the properties of the weld metal must match those of the base metal. The fusion method is also desirable where the casting is to be machined, tapped, or threaded in the weld zone (Fig. 13); where uniformity of rate of expansion and contraction throughout the casting is desirable; and where the casting is to be enameled or glass coated.

Although it might seem preferable to use the bronze welding method in order to eliminate the need for preheating the entire part, careful con-

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Committee on Welding Cast Iron, Gray Iron Division, A.F.A.



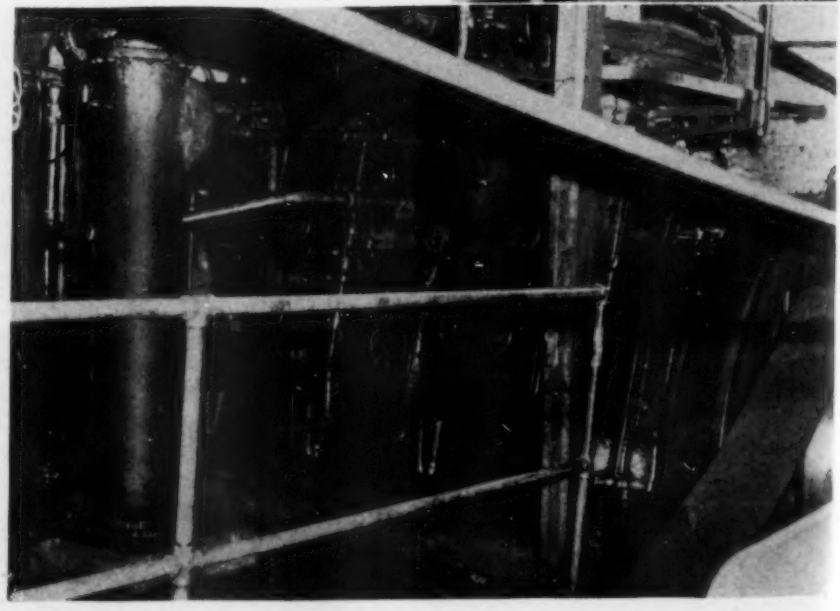
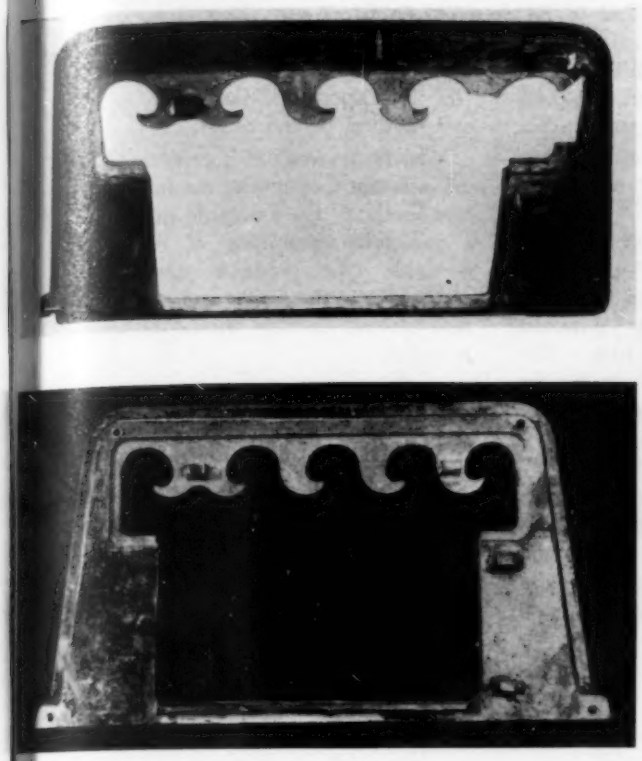


Fig. 8—(Right) The broken block for a 220-hp. diesel engine. Fig. 9—(Below) The block after it was bronze welded, using 175 lb. of bronze rod. Fusion welding would have been impractical for this repair.



Figs. 10 and 11—Cast iron fusion welding was the method selected to repair this ash-pit door for a large heating boiler (shown here before and after) because of the high temperatures to which the casting is exposed. Four different breaks can be seen in the upper illustration.

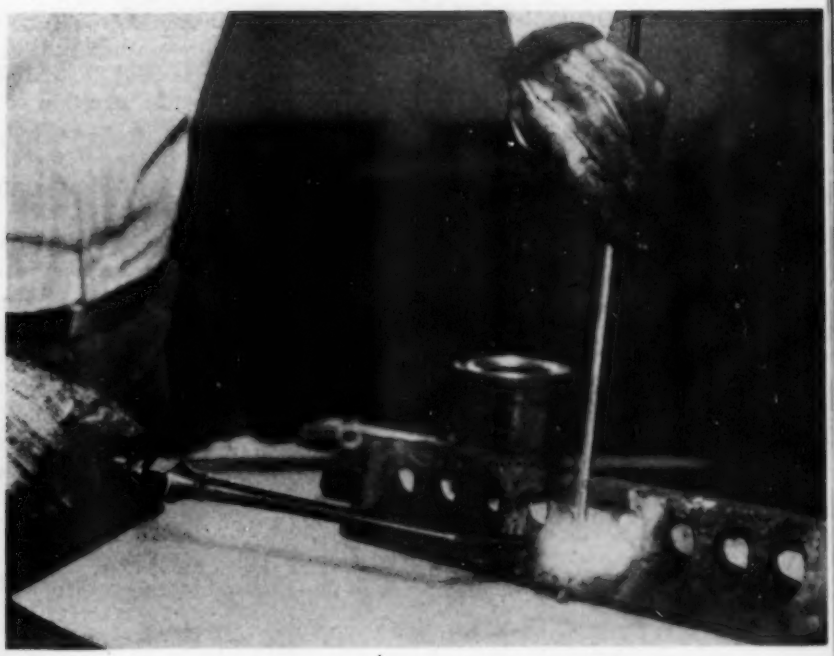


Fig. 12—Broken grate bars and other furnace and stove parts can be repaired by cast iron fusion welding.

sideration should be given to the factors just mentioned to determine if any of them make it imperative to use the fushion method.

Bronze Weld Metallurgy

Foundrymen familiar with fusion welding may wonder how a process such as bronze welding, in which actual fusion does not take place, can produce a strong joint. The basis for the bronze-welding process is that both brass and bronze will flow onto the properly prepared surfaces of higher-melting-point metals or alloys to give a bond or molecular union which has excellent properties.

Although the base metal is never actually melted in bronze welding, the unique characteristics of the bond between the bronze rod metal and the base metal are such that the results obtained are fully comparable to those obtained through fusion welding.

Bronze welding depends for its success upon conditions which will cause the molten rod metal of low surface tension to flow easily and evenly over the surface of the properly heated and chemically cleaned base metal just as water flows over a clean glass plate.

This spreading of molten metal from a bronze welding rod over a base material which is in a proper condition is known as the "tinning" of the base metal with the bronze. When the base metal is allowed to cool so that the bronze solidifies, this tinning action results in an extremely strong bond between the bronze and the base metal.

In addition to the tinning action,

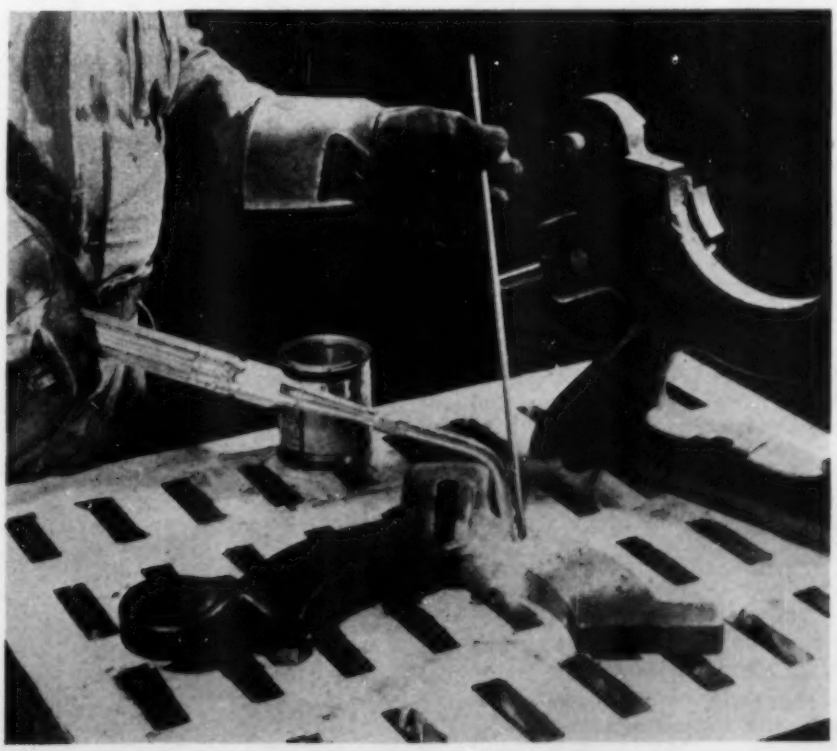


Fig. 13—This cast iron steady rest for a lathe was restored by fusion welding.

a slight interalloying of the constituents of the bronze and of the base metal will occur in a narrow zone at the interface of the bronze and base metal. This is apparently a slight reaction, not observable except under a microscope.

There also seems to be some evidence that the action of the molten bronze opens up the grain structure of the base metal to a certain extent and allows the bronze to penetrate along the grain boundaries. With cast iron as a base metal, it appears that during welding the bronze flows in to occupy the space left by the oxidation of some of the graphite flakes.

A description of the various types of cast iron is not within the scope of this paper. However, it is desirable to stress the necessity of determining what type of cast iron is to be worked on, since this may influence the selection of the welding method. A spark test, study of a freshly fractured piece, or observation of the action of the metal under the blowpipe flame are methods commonly used by welding operators to identify the type of cast iron.

In conclusion, it should be stated that there is no single standard method for welding cast iron. The decision to fusion weld or bronze weld a given cast iron part should be based on a consideration of a number of factors, including the following: (1) The type of cast iron. (2) The service conditions, including temperatures. (3) Subsequent finishing operations such as machining, painting, or enameling. (4) The size of the part to be welded. (5) Available preheating facilities. (6) The operator's familiarity with one method or the other.

Whichever method is preferred by an individual operator, the fact that two methods are available and that a judicious combining of the two methods can produce substantial economies in the repair and reclamation of iron castings should be kept in mind.

Acknowledgment

The material presented in this paper was accumulated from many sources and is largely a composite of the work and experience of the field engineers and service operators of The Linde Air Products Co.

Effect of Composition on Mechanical Properties of Sand Cast

COPPER-TIN-LEAD-ZINC ALLOYS

• Mechanical property determinations on a series of sand-cast copper-base alloys—calculated effects of composition changes—are presented graphically and in tabular form.

●

By W. T. Battis,
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SINCE practically all of the copper-base alloys in common use for sand castings are included in the quaternary system copper-tin-lead-zinc, it was believed that a survey of the properties of the alloys in this system might be helpful in reducing the number of alloys and would, also, provide some basis for composition limits in setting up specifications.

The literature contains only a few references on cast alloys, and the values reported, especially per cent elongation, are generally so much lower than those found in this investigation that it is believed that the casting techniques differed too much to allow comparison.

The more recent papers on sand casting alloys[1] do not cover changes in composition as much as different methods of casting, and where methods similar to those described here were used, the results compare very well for the few compositions reported.

Experimental Method

Clean muffled rifle shells were melted in a No. 45 clay graphite crucible, using a forced-draft coke-fired pit furnace. Clean, bright copper wire was then added, followed where necessary by electrolytic zinc and electrolytic tin. No charcoal, fluxes nor phosphorus were used.

Upon the attainment of proper

Table 1

MECHANICAL PROPERTIES OF SAND-CAST COPPER-TIN-LEAD-ZINC ALLOYS

Alloy No.	Composition, per cent Cu	Sn	Pb	Zn	Tensile Strength, psi.x1000	Yield Strength, psi.x1000	Elongation, per cent in 2 in.	Brinell Hardness
1	96.8	0	0	3.2	29.7	8.5	49	50
6	85.7	0	0.01	14.3	30.0	8.0	44	48
					29.6		50	
7	85.4	0	1.0	13.6	29.6	7.3	32	41
					30.5	7.3	33	
8	80.7	0	6.1	13.2	24.1	7.0	18	40
					24.5	6.5	20	
9	75.0	0	13.6	11.4	18.2	7.0	18	39
					18.1	7.0	13	
11	70.8	0	Nil	29.2	30.6	7.3	56	57
					31.2		49	
12	70.4	0	1.3	28.3	32.8	7.0	66	55
					32.9	7.2	67	
13	67.5	0	6.2	26.3	30.0	7.0	48	42
					30.5	8.3	52	
14	61.6	0	14.8	23.6	24.2	8.8	23	37
					25.8	9.5	27	
16	61.3	0	0.3	38.4	47.1	13.5	63	65
					44.8	13.5		
17	60.9	0	1.3	37.8	45.4	13.8	41	65
18	59.4	0	4.4	36.2	31.9	14.0	18	57
					38.8	15.5	25	
19	58.9	0	6.4	34.7	30.2	11.7	22	48
					29.8	11.7	21	
121	93.2	4.7	Nil	2.1	39.3	16.0	51	69
					38.7	15.5	51	
122	92.7	4.5	0.9	1.9	33.5		29	
					29.1		31	
123	89.4	4.3	5.2	1.1	35.1	14.5	32	53
					35.2	15.0	26	
124	85.5	3.7	9.9	0.9	33.6	13.0	13	50
					33.3	13.0	12	
26	89.9	4.9	0.2	5.0	39.2	15.8	51	57
					39.4	16.3	53	
27	89.4	4.8	1.2	4.6	37.2	16.0	39	57
					35.0	16.3	30	
28	86.0	4.6	6.1	3.3	36.8	16.3	32	74
					38.2	16.3	41	
29	81.4	3.7	13.1	1.8	31.4	13.3	27	53
					31.9	13.3	28	
31	80.7	4.8	0.1	14.4	39.7	15.0	38	58
					43.4	15.3	48	
32	80.3	4.5	1.3	13.9	43.5	15.0	49	60
					41.8		48	
33	76.6	4.3	6.5	12.6	37.0	13.5	42	76
					38.7	13.0	48	
34	71.0	3.8	14.9	9.9	31.7	13.5	28	66
					30.4	13.0	28	
36	66.1	4.6	0.03	29.3	38.6	24.0	1	93
					33.4		1	
37	65.9	4.4	1.1	28.6	33.1	23.5	2	93
					30.2	23.5	1	
38	63.6	4.3	6.3	25.8	29.8	21.0	3	77
					27.5		1	
41	89.0	9.5	0.2	1.3	46.0	19.0	42	69
					44.0	19.0	42	
42	88.4	9.4	1.3	0.9	42.2	19.0	36	69
					44.1	19.5	42	
43	85.0	8.5	6.2	0.3	42.0	19.5	39	61
44	78.8	7.1	13.5	0.6	35.0	17.5	30	53
					35.2	17.5	30	
45	71.8	3.5	24.6	0.1	24.5	15.0	18	49
46	85.2	10.0	Nil	4.8	47.8	20.0	30	69
					47.6	20.0	22	
47	84.7	9.8	0.9	4.6	41.8	18.8	25	69
					41.3	18.8	25	
48	80.6	9.4	6.1	3.9	43.5	17.8	34	65
					43.2	18.3	34	
49	74.7	8.3	13.5	3.5	39.2	17.0	31	61
51	76.2	8.5	0.1	15.2	27.7	24.0	2	86
					28.3	24.0	2	
52	75.4	8.4	1.2	15.0	25.0	21.5	2	74
					24.5	21.0	2	
53	72.3	7.9	6.9	12.9	26.0	20.0	2	69
					26.0	21.0	2	
54	65.2	7.2	16.7	10.9	25.0	18.5	4	65
					25.5	18.5	4	
56	61.9	7.8	0.02	30.3	40.5		0	158
57	61.6	7.8	1.3	29.3	39.5		0	158
58	59.3	7.4	5.6	27.7	39.0		0	158
151	68.2	10.6	0.07	21.2	34.3		0	143
					34.0		0	
152	67.7	10.3	1.1	20.9	33.0		0	143
153	65.4	10.2	5.3	19.1	32.4		0	130
					35.0		0	

pouring temperature, two molds were poured (lead-free). One per cent of chemical lead was then added to the balance of the metal in the crucible, the melt reheated to proper pouring temperature, and two more molds cast. The lead content of the remainder of the metal was then raised to 5 per cent and the metal reheated and cast. This was repeated for 10 per cent lead and 20 per cent lead contents.

The pouring temperature was measured with a chromel alumel closed-end thermocouple and a portable potentiometer, and was predetermined by adding 150° F. (± 20° F.) to the liquidus temperature of each alloy as taken from the literature.[2, 3]

The test bar casting was of the standard Webbert type with a 5/16 in. fin feeding the whole length of the test bar. It was cast vertically (test bar directly below the riser) through a one-inch diameter sprue on top of the riser, the metal dropping from the ladle directly into the bottom of a mold of baked core sand. The castings were shaken out of the mold in from 30 to 45 min. and allowed to air cool to room temperature.

It was found to be impossible to produce sound zinc-free test bars without resorting to radical changes in the melting or casting procedure, so it was decided to accept the lesser evil of making a small zinc addition and extrapolating the curve to zero per cent zinc.

The castings were wire-brushed to remove sand, and the test bar portion was cut off. Samples for chemical analysis were obtained by drilling halfway through the riser just above the web connecting it to the test bar. Each alloy (two castings) was analyzed for copper, tin and lead, and the zinc content was taken by difference (Table 1).

Standard 0.505-in. diameter threaded bars were machined from the casting and tested. Stress-strain curves were made on all bars, using an extensometer reading to 0.0001 in. The yield strengths reported are the unit loads at 0.5 per cent elongation under load.

After fracture, the threaded ends of the test bars were polished for

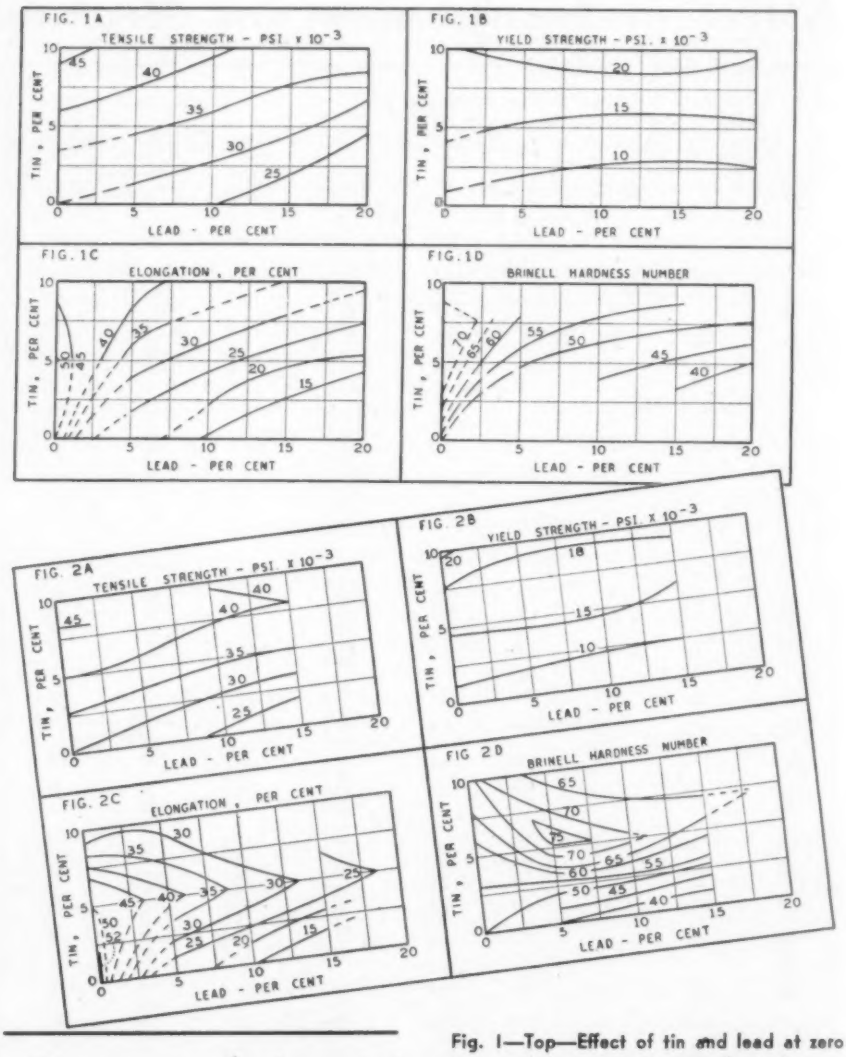

Fig. 1—Top—Effect of tin and lead at zero per cent zinc content on mechanical properties of copper-base alloys.

Fig. 2—Bottom—Effect of tin and lead at 5 per cent zinc content on mechanical properties of copper-base alloys.

This paper was secured as part of the Program for the 1945 "Year-Round Foundry Congress" and is sponsored by the Brass and Bronze Division of A.F.A.

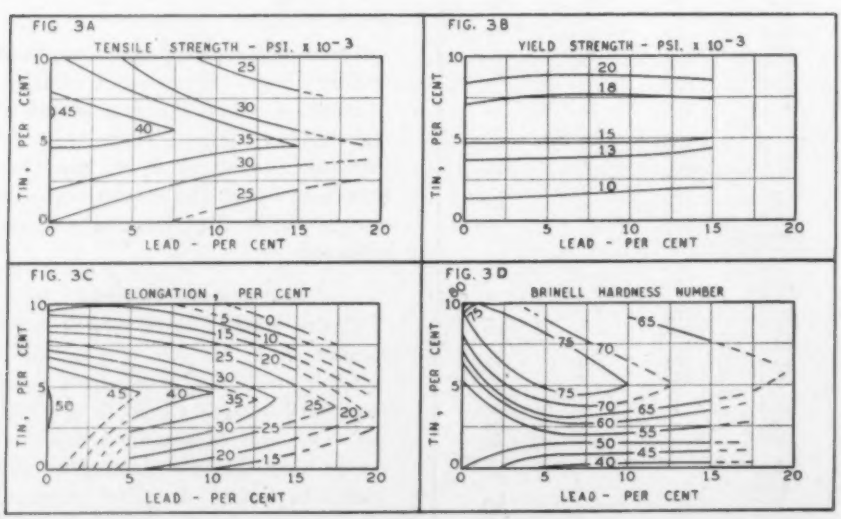

Fig. 3—Effect of tin and lead at 10 per cent zinc content on mechanical properties of copper-base alloys.

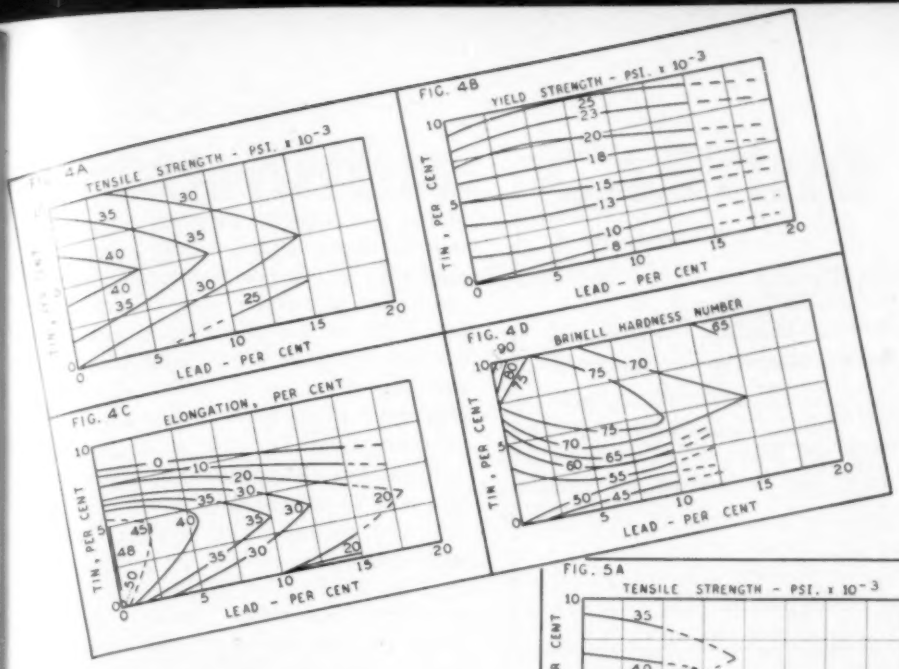

Fig. 4—Above—Effect of tin and lead at 15 per cent zinc content on mechanical properties of copper-base alloys.

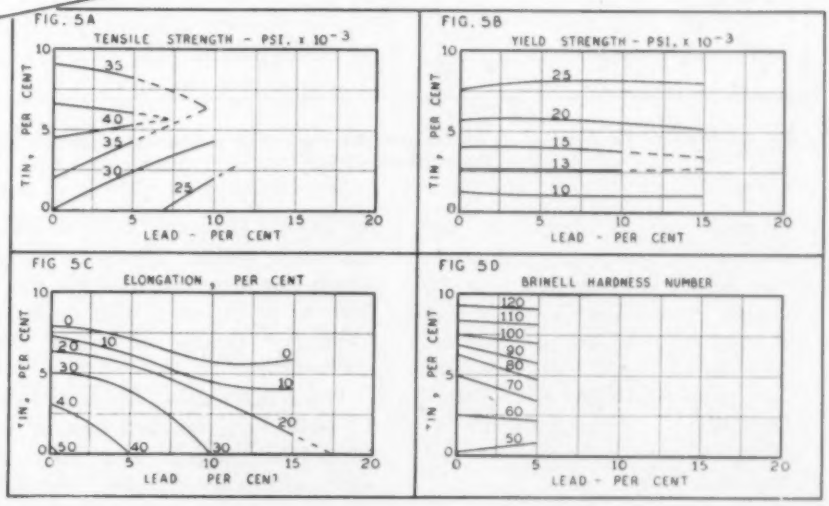

Fig. 5—Right—Effect of tin and lead at 20 per cent zinc content on mechanical properties of copper-base alloys.

Brinell hardness determinations and microscopic examination. Brinell impressions were made with a 10-mm. ball, using a 500-kg. load for 30 sec. For microscopic examination, the specimens were etched with potassium dichromate and/or ammonium hydroxide and hydrogen peroxide.

Presentation of Data

The plan of research consisted ideally in making 12 lead-free alloy bases, each containing exactly the nominal amounts of tin and zinc. Thus a curve could be drawn showing the influence of zinc on the properties of alloys containing 0, 5.0 and 10.0 per cent of tin with points at 0, 5.0, 15.0 and 30.0 per cent of zinc. Similar curves also could be obtained from the same points showing the effect of tin on the properties of alloys containing, say, 15.0 per cent of zinc with points at 0, 5.0 and 10.0 per cent of tin. Intermediate values then could be read from the curves.

Since this degree of accuracy in compounding alloys is almost impossible to attain without pre-alloying, especially with high zinc contents, only routine precautions in weighing and melting were observed and, after analysis, the properties of an alloy containing only 29.2 per cent of zinc were modified by calculation to the properties of the nominal composition (30 per cent).

It also will be noted that, ideally, additions of lead would not change the copper-tin-zinc ratio but only the percentage of each. Again it is impossible to attain this ideal and, as lead was added and the metal reheated, the ratio of copper-tin-zinc did change.

There are, therefore, two major deviations from the ideal which must be taken into account:

A. Deviation from nominal zinc composition (lead-free).

B. Deviation from nominal tin composition (lead-free).

C. Change of copper-tin-zinc ratio during lead additions.

Methods Used

The method used may be broken down into steps as follows:

Step 1: Calculate the "lead-free analysis" of each alloy, or make the copper, tin and zinc contents equal 100 per cent.

Step 2: Plot the properties of each base alloy versus actual lead content, assuming that Deviation *C* does not exist, i.e., the copper-tin-zinc ratio is assumed to be constant.

Step 3: Plot properties versus actual percentage of zinc at 0, 5 and 10 per cent nominal tin with separate curves for 0, 5, 10, 15 and 20 per cent of lead (a total of 15 curves for each property), the values being read from the curves of properties versus lead content *(Step 2)*. This step assumes that Deviations *B* and *C* do not exist.

Step 4: Plot the properties versus actual percentage of tin at 0, 5, 15 and 30 per cent nominal zinc with separate curves for 0, 5, 10, 15 and 20 per cent of lead (a total of 20 curves for each property), the values being read from the curves representing properties versus lead content *(Step 2)*. This step assumes that Deviations *A* and *C* do not exist.

The purpose of making these admittedly erroneous graphs *(Steps 3* and *4)* is to observe, in a semi-quantitative way, whether for each alloy the trend or slope of the several curves is such that chemical deviations from the nominal composition are introducing significant errors.

Step 5: Corrections for Deviations *A, B* and *C* are made for each sample as follows:

(a) Deviation *A*: Determine from the curves of *Step 3* the increment of each property between the actual zinc content and the nominal zinc content.

(b) Deviation *B*: Determine a similar increment of each property between the actual and nominal tin content from the curves of *Step 4*.

(c) Determine the net effect

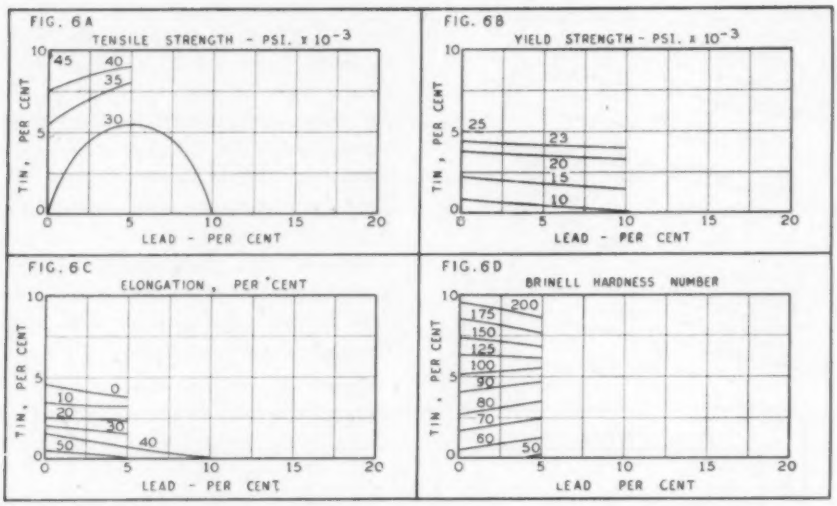

Fig. 6—Effect of tin and lead at 30 per cent zinc content on mechanical properties of copper-base alloys.

of each pair of increments and correct each experimental property datum accordingly. This obviously corrects Deviations *A* and *B* and, since the net result of the correction is to establish the nominal copper-tin-zinc relationship, Deviation *C* is automatically reduced to zero in each case and thus eliminated.

Step 6: The "uncorrected" curves described in *Steps 2, 3* and *4* were again plotted, using the values obtained in *Step 5*.

In all of these calculations, the "lead-free analysis" or copper-tin-zinc ratio was used.

From the curves described in *Step 6*, corrected to nominal composition, Figs. 1 to 6, inclusive, were obtained after calculating the lead content back into the composition. Since zinc has less unit effect on properties than does tin or lead, these sections were made at constant zinc values. For zinc contents between these even values, interpolation must be resorted to.

Discussion

It is acknowledged that the properties of a very wide range of compositions have been reported using only a relatively small number (47) of alloys. However, it is believed that the graphs represent values which are correct within the variations to be expected with duplicate specimens (about ± 5 per cent maximum).

The actual values obtained (Table 1) have been checked against the applicable curves, and they all agree within these limits. Although the effect of impurities is not known, the properties obtained on commercial alloys by the same method of casting are in substantial agreement with those reported here.

While a detailed discussion of each graph will not be attempted, some general remarks are in order.

Changes in direction of the lines are due chiefly to the appearance of new phases, although some changes indicate a difference in the degree of coring present.

Line Direction

From the lack of uniformity of direction of the lines, it is evident that the use of a "coefficient of equivalence" to simplify an understanding of the system is inadvisable except within very narrow limits. It is also evident that if such a coefficient be used within satisfactorily narrow limits for one property, it may not apply to another property.

The number of alloys studied does not permit drawing the boundaries of the phase fields. In general, the tin-free alloys consist of all alpha, except for the one containing 40 per cent of zinc, which also contains beta. All of the alloys made containing tin consist of alpha plus partially decomposed beta (alpha plus delta), the amount depending on composition.

In the low-tin and low-zinc alloys, this beta is present because of coring, and the all-alpha equilibrium state can be established by annealing. As the amount of beta (alpha plus delta eutectoid) increases, the alloys become harder and more brittle; and when the beta becomes continuous, the elongation drops to zero.

With high tin and zinc content, the addition of the higher amounts of lead resulted in two liquid layers. This was immediately obvious when the castings were shaken out, and these bars were discarded. Not enough alloys of this type were made to allow drawing the two-liquid phase boundary lines.

Summary

Tensile strength, yield strength, per cent elongation and Brinell hardness have been determined on a series of sand-cast alloys, and the effect on these properties of changes in composition has been calculated and presented graphically for the quaternary system copper-tin-lead-zinc, within the limits of commercial use.

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ALUMINUM CASTING STABILITY

REPORT OF THE A.F.A. COMMITTEE ON

Dimensional changes in aluminum alloy castings... caused by density changes . . . residual stresses resulting from plastic deformation . . . selection of conditions and treatments to attain stability.

Aluminum and
Magnesium Division

REPORTS from various sources indicate that difficulty is sometimes encountered with aluminum castings that are machined after heat treatment. The parts after machining are found to have changed dimensions. Since this problem is of particular importance to some producers, a subcommittee was appointed to investigate the problem and to submit suggestions.

This committee has contacted persons familiar with the problem and the information submitted by them has been of great help in preparing this report. Much of the information may be familiar to those who have been interested in this problem previously, but it is given in this report for the benefit of those who are not so familiar with the problem. The information is given as closely as possible in the wording and manner in which it was submitted.

The committee wishes to extend its sincere appreciation to those who were kind enough to submit the suggestions and data reported.

Committee Report

C. C. Hitchcock (R. C. Hitchcock and Sons, Minneapolis) submitted the following information:

"The problems we are experiencing in dimensional stability probably can be attributed mainly to internal stresses set up by quenching heat-treated alloys. We know that some instability is caused by work hardening of the surface when tools get slightly dull.

"We have been carrying on many experiments with different annealing temperatures after the quenching operation and find that this helps to relieve our problem."

A brief outline of the deep-freezing process often used to overcome the difficulty was given by Mr. Hitchcock as follows:

"The deep-freezing process consists merely of taking the casting down to below 100° F. below zero and then raising the temperature to 200° F. and repeating the process five and six times. The only advantage that I can see to this is molecular movement due to the change of temperature which tends to put at rest any casting strains."

The committee presented two other questions to Mr. Hitchcock: (1) Over what temperature range are the castings expected to have dimensional stability? (2) Since much of the dimensional instability is attributed to internal stresses set up by quench heat treatment, what results have been obtained with non-heat-treated alloys?

Mr. Hitchcock replied as follows:

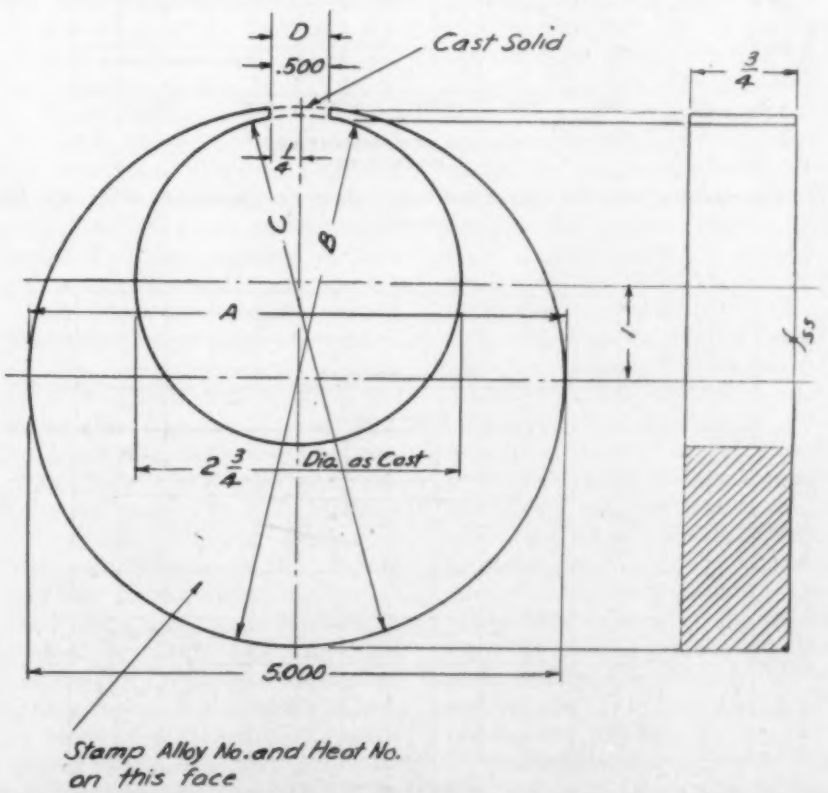


Fig. 1—Sketch of distortion test specimen used for detection of dimensional changes.

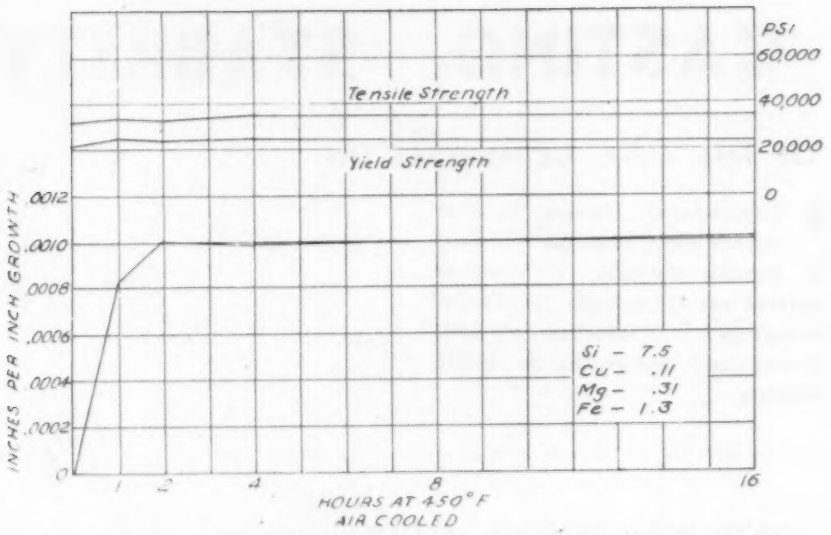


Fig. 2—Growth curve of single standard ¼-in. diam. die cast test bar.

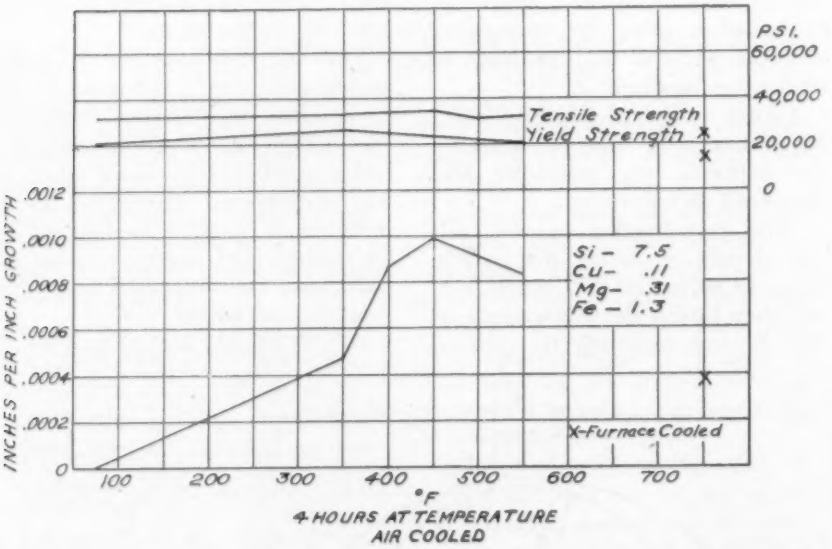


Fig. 3—Heating and cooling conditions effect on aluminum alloy test bar growth.

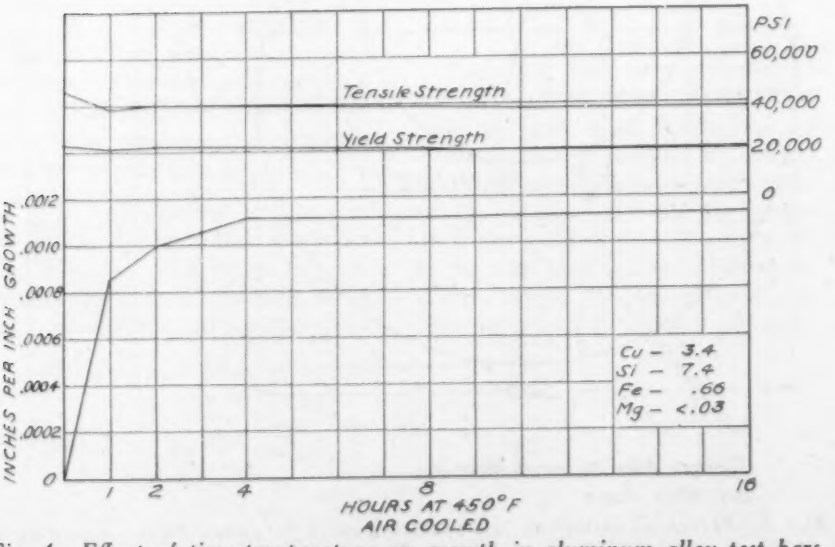


Fig. 4—Effect of time-temperature on growth in aluminum alloy test bars.

"The temperature range in which we must maintain stability in our castings is from 212° F. to 40° F. below zero.

"We have not done a great deal of experimenting with non-heat-treated, high strength alloys, but our experience with commercial grade as-cast alloys such as 108, 212 and the like, has not been satisfactory. This we attribute to the fact that unless the casting sections are absolutely uniform, strains are set up in the casting processes which will relieve themselves over a long period of time. We have, therefore, gone to heat-treated alloys, feeling that the stresses and strains resulting would be far less detrimental than those incurred in the casting process. This is more true in castings where there is considerable core.

"Our trouble does not lie 100 per cent in instability after the article is in the field. A great deal of it occurs during the fabrication or machining. In some instances we have found that the machining and jigging of the castings were at fault, but we are not satisfied that the ultimate in casting stability has been reached."

Heating and Cooling

Wayne Martin (then with Sperry Gyroscope Co., Flushing, N. Y.) submitted the following information:

"We use 5 hr. at 450° F. heat treatment followed by air cooling at the expense of the resultant mechanical properties. In no case over a period of years has this treatment failed to produce the best of stability, and it has been used on dimensionally unstable castings of 195 and 356 alloys in the T6 condition and made them stable.

"In many cases it is conceivable that in some instances such a treatment would be undesirable because impact properties and other properties often deteriorate with such treatment. In the case of some thermostats we have, on advice of Louis Kempf (Aluminum Co. of America, Cleveland), gone to one hour at 750° F., which annealed the casting soft, but the stability was certainly there.

"On die castings we use 16 hr. at 450° F. and appear to have dimensional stability. Apparently silicon-aluminum die castings present the greatest problem relative to stability. Temperatures higher than 450° F. we feel should not be used on thin-

wall die castings because the yield strength drops off fast.

"We feel that dimensional stability of aluminum castings is associated with three factors. They are as follows:

"(1) *Growth in silicon alloys.* A casting hardened at 320° F. will grow in volume considerably if heated to temperatures approaching 500° F. This has been checked several times. We presume that surface heat generated in machining sometimes causes localized growth with resulting dimensional change.

"(2) *Volume changes due to precipitation hardening.* We have always assumed that this could cause volume change and thus dimensional unstability. We have never traced any of our trouble to this cause for we have never machined castings until after they have been fully precipitated by heat treatment.

"(3) *Locked-up stresses from casting, quenching, or straightening.* We have definitely found cases where 356 and 195 alloys have been unstable due to quenching in water at too low a temperature. The 320° F. heat treatment was not sufficient to stress relieve the castings in this case, but the 450° F. treatment for 5 hr. did work. We feel that most of the trouble with dimensional unstability results from quenching stresses or subsequent straightening stresses set up in straightening castings that have warped out of shape during the solution heat treatment.

"We are, at the present time, working on improvements of a high-zinc alloy which can definitely be stabilized by heat treatments in the range of 400-700° F. and still show mechanical properties in the neighborhood of 25,000 psi. yield strength and 40,000 psi. ultimate strength with 4 per cent elongation."

Instability Causes

In order to clearly establish the type of instability and the relative amount of it, the committee asked Mr. Martin to answer two questions: (1) How do you test for stability? (2) Is the instability to which you refer due to the natural coefficient of expansion or is it in excess of the normal change due to the coefficient of expansion? Mr. Martin's answer was as follows:

"We do not know of any good means to check dimensional stability from all possible causes, except by use of intricate castings. The instability to which we refer is not temperature coefficient of expansion, but a permanent change in dimensions at constant temperature. We have had 356T6 castings move as much as 0.005 in. in 20 in., but in many of our parts we are interested in holding tolerance stable to as close as ±0.0001 in.

Locked-up Stresses

"Most of the instability shows itself after rough machining, which makes it appear, at least in our case, as if it were a matter of locked-up stresses. Assuming the worst possible case of this type, we would have an aluminum alloy with an elastic limit of approximately 10,000 psi. Assuming that a very drastic quench was applied, causing a locked-up stress in excess of the elastic limit, the casting would be subject to plastic deformation to the extent of the stress in excess of the elastic limit, leaving a locked-up stress of 10,000 psi.

"Then again, assuming the worst possible case, that is, a machining operation which would cut away enough metal to permit the complete removal of the 10,000 psi. locked-up stress in the outer fibres, based upon a 10,300,000 modulus, the strain resulting from the 10,000 psi. stress would be 0.001 in. per in. If this extreme case had been applied to our casting over 20 in., the movement could have been 0.020 in.

"Since this casting had been aged at 320° F., the locked-up stress could not have been 10,000 psi., because the elastic limit at that temperature is considerably lower and the stress would have been relieved by that percentage. It would appear that the 0.005-in. movement could fall very well within the probable expectation of what would happen, as a result of a quenching stress equal to the elastic limit.

"As to measurement of this type of instability, a very good paper was presented recently by A. E. McPherson, of the National Bureau of Standards, Washington, D. C., before the May 20 meeting of the Society for Experimental Stress Analysis, in Boston. By use of SR4 gages and very careful cutting of a magnesium casting, he was able to find a locked-up stress of 4,000 psi. in a casting subject to failure at that point.

"The same technique could be used to determine dimensional instability as the result of locked-up stresses, but probably could not be used to determine volume changes due to precipitation hardening, or changes due to growth at elevated temperatures, because of the instability of the SR4 gages, over a period of time."

Sperry Gyroscope Co. has reported the use of the distortion test specimen shown in Fig. 1, which is similar to that used for tool steels:

"The specimen is cast and the dimensions *A, B,* and *C* are measured immediately after casting. At the time at which a distortion test is desired a cutter of ½-in. width is used to slot through the thin portion of the casting. If there is any distortion after cutting, this is detected by noting the change in dimensions *A, B,* and *C,* and also by taking a fourth measurement *D* which indicates how much the ½-in. gap has increased."

This test was used on an Al-Zn-Mg alloy (40E) and indicated no distortion after either 4 weeks aging at room temperature or after heating to 360° F. to accelerate aging. (This alloy requires no solution or quench heat treatment.)

Distortion Tests

Mr. Martin later added the following comment:

"This tool steel type of specimen was used on several solution heat-treated alloys and showed them to be stable. Later castings of the same alloy gave trouble from dimensional unstability in manufacturing. The errors in measuring this specimen are probably greater than the tolerances required on many castings. I do not believe that this test is of much value as shown here."

In reviewing Mr. Martin's report, Mr. Jung (Sperry Gyroscope Co.) extended the following information:

"Curves (Figs. 2, 3, and 4) which were plotted from results obtained from single standard ¼-in. diameter die casting test bars may be of interest. All growth is attributed to precipitation. No signs of locked-up stresses which could account for any appreciable amount of the growth were found. As a result of these tests, we are now heating our die castings for 5 hr. at 450° F. for dimensional stability.

"Similar dimensional tests on sand-cast 40E and ternalloy 6 indicate that dimensional changes from aging

will be considerably less than 0.002 in. per in.

"Tests made on alloy 356 sand-cast distortion specimens which were described by Mr. Martin have indicated the following:

"(*a*) Growth from aging will reach a maximum of approximately 0.001 in. per in. at 450° F. after casting. Little if any locked-up stresses which may cause distortion will be present.

"(*b*) Aging of this alloy after solution heat treatment will not cause any appreciable growth. However, considerable locked-up stresses, which will not be relieved after heating at 310° F., may be present. This can cause considerable distortion when the castings are machined. The heat treatment needed to remove these stresses has not been determined as yet. At the present time we are using 5 hr. at 450° F. and accepting lower mechanical properties if stability is required."

R. E. Ward (Eclipse Pioneer Div., Bendix Aviation Corp., Bendix, N. J.) submitted the following information:

"The first tests that we conducted on stability of castings that I remember were on sample castings which were made up of non-heat-treated alloy (8 Zn, 0.90 Mg, 0.50 Cr, and 0.15 Ti). The tests were comparatively simple but produced results which were satisfactory. We poured an intermediate housing casting which is a cylindrical part of about ¼-in. wall thickness having a diameter at one end of about 7 in., a diameter at the other end of about 4 in., and neck down in the center to about 3-in. diameter. We cast the part, machined the end diameters, performed the desired heat treatment (aging) and then cut the part longitudinally and measured any distortion of the diameters.

Tolerances Maintained

"The problem of light alloy casting stability has been one we have had to face constantly since many of our castings are machined as close as +0.003 in. and −0.0 in. and, as is well realized, complete stability is necessary to maintain these tolerances. We have found that a stress relief anneal at 375° F. for 2 hr. performed between the rough and finish machining operations gives us the desired stability, provided the finish machining operations are done with sharp tools and the castings are jigged in the machines without distortion.

"When such extremely close dimensions as those mentioned must be held, we find it advantageous to do the finish machining after the paint and baking operation since a paint bake of one hr. at 300° F. might cause distortion. Whether or not it does cause distortion has never been definitely decided to the satisfaction of everyone since whenever tests are conducted we have found no distortion, but when close machining is done after baking in production it is reported that the castings sometimes change dimensions.

"It is believed that any thin-wall casting of fairly large dimensions is a satisfactory one for conducting distortion tests, but it must be borne in mind when conducting these tests that the differential coefficient of expansion of steel measuring instruments on aluminum or magnesium is so great that a few degrees change in room temperature will affect the tests to the point where they may be worthless."

Temperature Ranges

The committee requested Mr. Ward to answer three more questions: (1) Within what temperature ranges is it usually desirable to expect casting stability? (2) If most of the distortion is due to locked-up stresses caused by heat treating, is it possible that high strength non-heat-treated alloys artificially aged at 356° F. may help to overcome the problem? (3) Where castings are annealed at say 375° F. before machining, what is expected in the way of strength properties?

Mr. Ward's answers to these questions were as follows:

"In manufacturing aircraft accessories, it is desirable to expect casting stability within the temperature range of −75° F. and +350° F. This is to take care of cold weather operations and operation at about the temperature of the engine oil. Naturally, not all castings are subject to as high a temperature as 350° F., but in the case of pumps temperatures of even 400-425° F. are not unusual.

"It was mentioned that several companies expressed the opinion that most of the distortion is due to locked-up stresses caused by heat treating. This may be true in solution-treated castings but, as stated in a previous letter, we have never experienced distortion of solution treated and aged castings stress relief annealed between the rough and finish machining operation, even when holding extremely close tolerances.

"When castings are stress relief annealed at 375° F. before final machining, we do not experience any appreciable drop in physical properties. As a matter of fact, we still age 195 aluminum alloy in the foundry at 375° F. and follow up with a stress relief anneal when necessary.

"Sometime ago we considered eliminating the aging after solution treatment in the foundry and using the stress relief anneal between finishing and final machining as the aging treatment so as not to overage the castings. This has worked satisfactorily, but we have not as yet changed all parts since it requires a considerable number of drawing changes and since we are at present meeting the desired physical properties.

"For a number of years we have been keenly interested in the high strength, non-heat-treated alloys which are artificially aged for 10 hr. at 356° F., but we have felt that certain drawbacks such as castability and the necessity for close control of impurities and balancing of alloying elements have made this type of alloy less desirable than the presently used high temperature solution-treated alloys."

Support During Machining

Dr. David Basch (then with General Electric Co., Schenectady, N.Y.) submitted the following:

Lack of support during machining was found to be a great cause of warpage during machining. Tool pressure deforms low yield strength alloys unless the parts are properly supported.

On non-heat-treated alloys a stabilizing treatment of 6 hr. at 275° C. (527° F.) is used. Alloy 43 is held 3 hr. at 600° F. This treatment is not used on heat-treated alloys due to the consequent lowering of physical properties.

Alloy 40E was stable after machining following a 10-hr. age at 356° F. Higher aging temperature destroys physical properties.

Alloys 355 and 356 are held at 440° F. for 8 hr. for stress relief,

but yield and tensile strength are considerably reduced.

Because of the possibility of cracking castings in straightening operation following quench heat treatment and age (T6), General Electric Co. asks that all parts be preheated in boiling water before straightening.

Grogan and Clayton[1] investigated the dimensional stability of heat treated aluminum alloys and arrived at the following conclusions:

1. Changes in dimension occurring after heat treatment were much larger in wrought "Y" alloys and duralumin than in those of the cast series.

2. Considerable dimensional changes occur when material quenched in cold water is machined. Changes were greatest in "Y" alloy, less in duralumin, and 25S alloy, and still less in the copper-silicon alloys.

3. In "Y" alloy and duralumin quenching in cold air reduces the dimensional changes which occur on machining as compared with cold water. Quenching in boiling water reduces them to relatively small proportions.

4. These dimensional changes do not appear in annealed material.

Effect of Aging

Frontier Bronze Corp., Niagara Falls, N. Y., reported a test which was made by one of its customers on a large 40E casting. Due to government restrictions covering the article tested the complete story cannot be given, but a summary is presented herewith.

A large reflector casting of 40-in. diameter and dished like a searchlight reflector was cast and artificially aged 10 hr. at 356° F. Prior to machining, the casting was fastened on a machining jig and set screws placed at various parts of the casting. The casting was then machined over the entire reflector surface, which gives a rough idea of the amount of metal removed.

After the machining was complete dimensions were checked at each of the set screws. A 0.001-in. gage was used for this check, and at no place was the change in dimension large enough to permit passage of the gage. It was roughly estimated that any dimensional changes were in the neighborhood of 0.001 inch.

Since there may be some interested persons who are not familiar with the "deep-freeze" process of relieving stresses, a brief review is given herewith of the process as described by G. F. Forsthoefel[2]:

Down to —50° F. is used to stabilize metal in precision gages or instruments. Sub-zero temperature is applied 4 to 6 hr. The part is then raised to room temperature and then again subjected to sub-zero for 4 to 6 hr. This process may be repeated four to six times. Some gage manufacturers add a heating cycle after the sub-zero period by inserting the part in boiling water after each cooling period.

The process is said to result in alternate expansion and compression of molecules whereby after repeated cycles the metal finds a stabilized molecular condition. By stabilization it is not meant that the metal will not expand or contract with temperature changes, but it does mean that all internal strains have been relieved so that when the gage is subjected to repeated temperature changes it will always come back to the exact size it had at the time it was finished at a given temperature.

Summary

Howard Rowe, committee member, made the following summary of the data:

"There are two causes, and only two, of lack of dimensional stability of aluminum castings. There are (1) density changes involved in changes of concentration of constitutents in the aluminum solid solution, and (2) residual stresses resulting from plastic deformation. Evidence of dimensional instability from either of these two causes may be the result of the algebraic sum of both efforts acting independently.

"In general, the condition of a saturated solid solution in most commercial aluminum alloys is the condition of maximum density. Precipitation of constituents from a solid solution is, therefore, accompanied by a decrease in density or permanent growth. Maximum mechanical properties usually are attained at a density lying somewhere between the maximum of the solid solution and the minimum of the completely annealed structure.

"Various compromises can be struck between maximum mechanical properties and complete stability by the selection of proper conditions of the precipitation or aging treatment. Generally speaking, the higher the temperature and the longer the time of the precipitation treatment, the nearer the structure comes to complete dimensional stability.

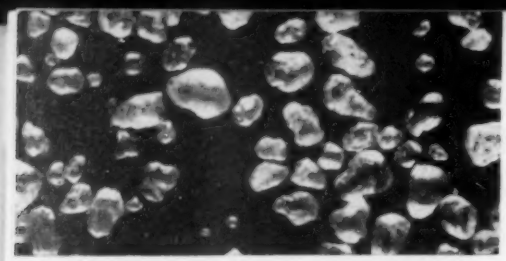
"The plastic deformation resulting in residual stresses, which may cause distortion on removing a part of the structure by machining or otherwise, may arise during quenching from a high temperature solution treatment or from straightening of the casting at temperatures below the annealing range. Welding, which may involve rapid cooling from elevated temperatures, also may produce plastic deformation resulting in residual stresses. Similarly, the restrained cooling of a casting in a mold may give rise to plastic deformation which will result in residual stresses.

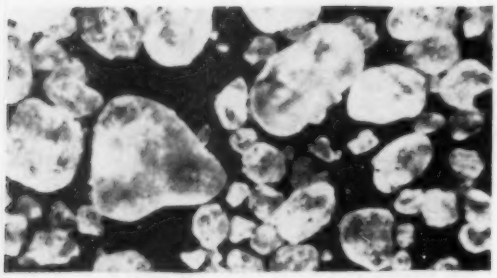
"Residual stresses may be relieved by heating the casting to temperatures up to about 750° F. followed by slow cooling to room temperature. Such a treatment will reduce the residual stresses to substantially zero with, of course, a sacrifice in the mechanical properties obtainable. Here again a compromise may be achieved by heating at temperatures below the annealing range. The higher the temperature and the longer the period of time, the greater the reduction in residual stress."

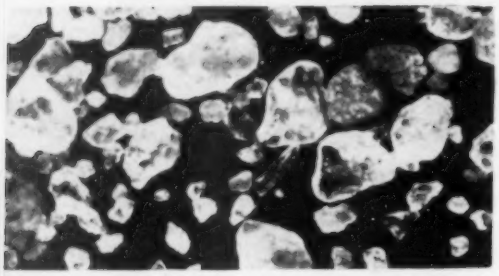
Personnel of the Committee on Casting Stability, Aluminum and Magnesium Division, is as follows: H. Brown, *Chairman*, G. H. Starmann, H. J. Rowe, and R. E. Ward.

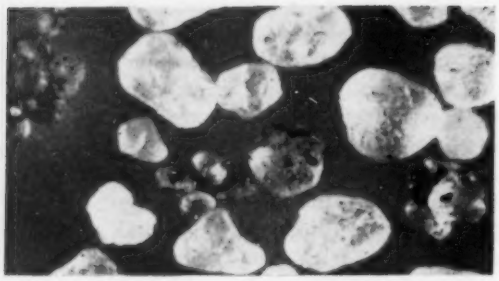
[1] J. D. Grogan and D. Clayton, "Dimensional Stability of Heat-Treated Aluminum Alloys," *Journal*, Institute of Metals, vol. 45, p. 157 (1931).

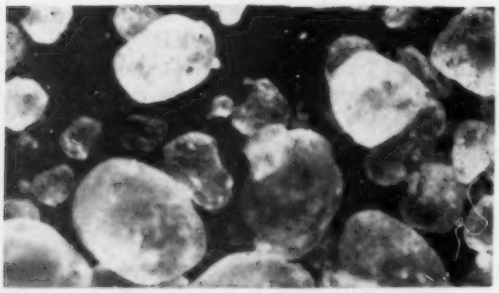
[2] C. F. Forsthoefel, "Sub-Zero Temperatures in Industry," *Refrigeration Engineering*, vol. 46, no. 3, Sept., 1943, pp. 164-7.

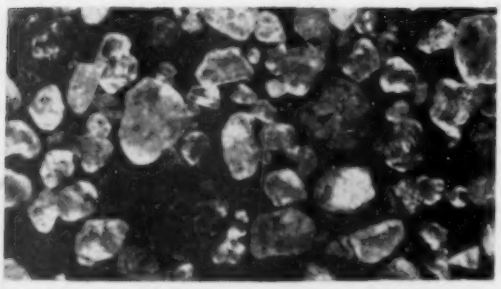












MICROSCOPE AND CAMERA

in the study of

FOUNDRY SAND

A. C. Den Breejen
Sand Technician
Hydro-Blast Corp.
Chicago

USE OF THE MICROSCOPE and camera in connection with various divisions of scientific and industrial work is rapidly increasing. Their use has greatly increased the wealth of knowledge in such fields as medicine, chemistry, biology and metallurgy, and has given the workers in these fields new tools with which to work and a means to permanently record their findings.

The sand laboratory of the average foundry, however, has not fully realized the importance of these tools, or has been diverted from their full usage due to an erroneous conception that complicated and costly equipment is necessary and that a high degree of technical knowledge of optics, chemistry and photography is required to produce satisfactory results. Nothing could be further from the truth! If a man can take a picture with a hand camera, follow the printed directions on a package of photographic chemicals, and if his company will spend $150 to $200 he will have the requirements and tools to begin work.

The investment on the part of the company is one it will never regret. It will pay for itself tenfold in the many applications in which it can be employed usefully. The following article, in answer to numerous requests from sand technicians, laboratory workers and sand

Fig. 7—Photomicrographs of new sand at 25 diameters (from top to bottom):

Small grains but variation in size not great.

Note low clay content present and variation in size of grains.

Fragmentary particles present.

Conglomerate grains present in this bank sand.

New washed sand.

Darker grains contain appreciable amounts of iron oxide as part of the silica make-up.

Note light clay splotches.

Foundry sand laboratories, in general, have overlooked the possibilities offered by microscope and camera . . . simple, inexpensive tools . . . for study of a basic metal — casting material . . . foundry sand.

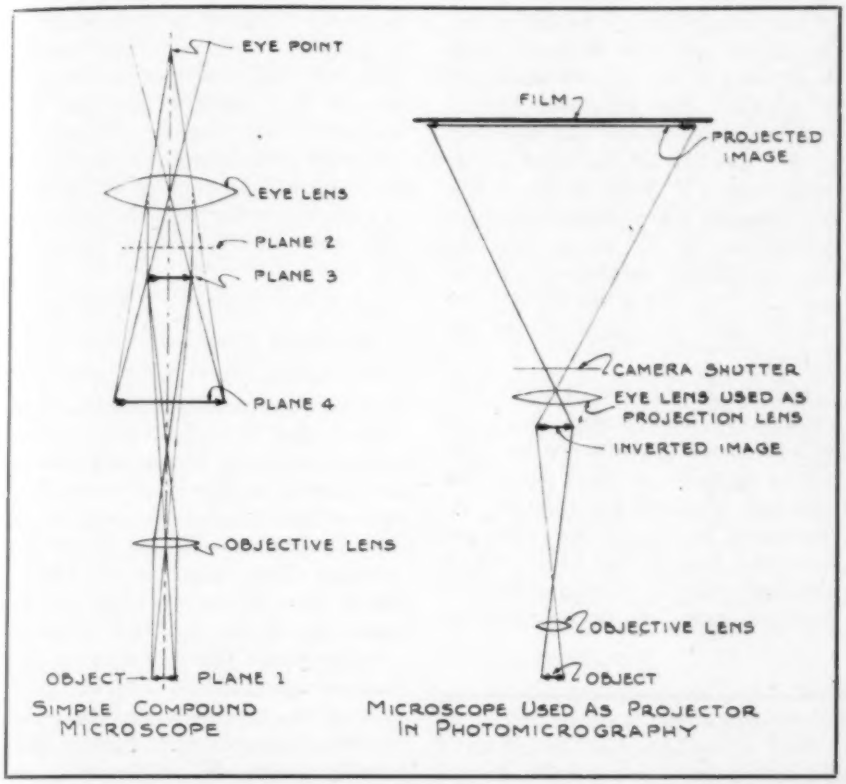


Fig. 1—Diagrams showing principles of simple compound microscope and its use with camera in photomicrography.

users, will be written with a viewpoint to simplicity, as directly to the point as possible and as informative as is consistent with the actual requirements needed to produce satisfactory results. Readers who wish to delve deeper into the subject will find a reference list of publications at the end of this article.

The microscope used in the visual examination of foundry sands need not differ greatly from that used in the botany and zoology classes in high schools. Microscopes

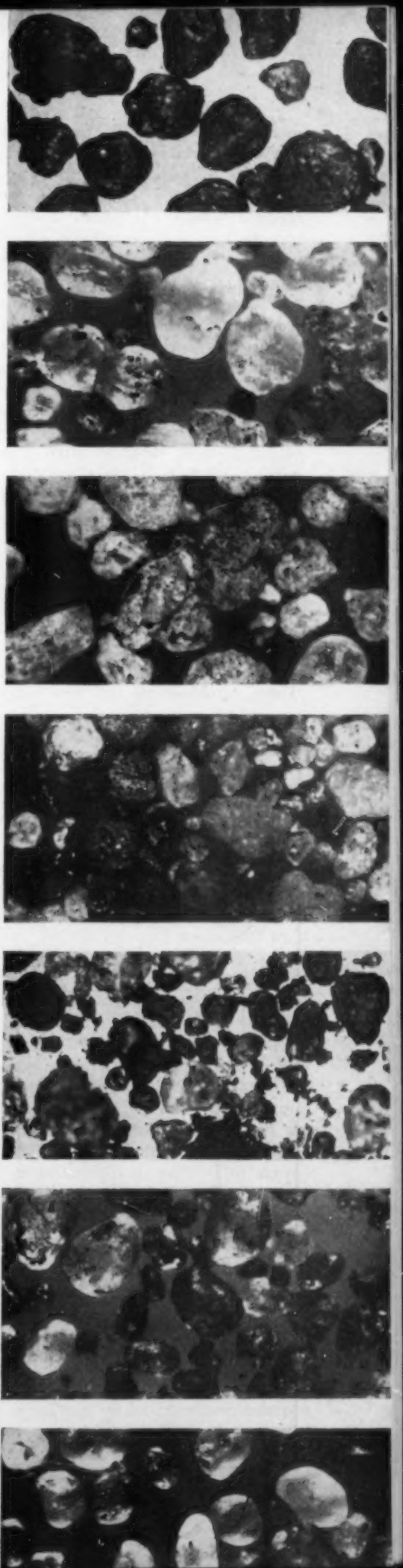


Fig. 8—Photomicrographs of sands at 25 diameters (top to bottom):

Used core sand. Note carbonized oil coating on grains.

Reclaimed core sand. Surface of grains and crevices plugged with carbonized or oxidized oil not wholly removed.

Ignited refuse sand. Spongy clay coating on grains partially calcined.

Used molding sand. Clay coating on grains and some black, shiny grains from core sand contamination.

Discarded molding sand. Note presence of fines and graphite-clay coatings on grains.

Used core sand. Note appearance of some almost clean grains showing result of improper mixing or removal of oil film by heat in proximity of core-metal interface.

Reclaimed core sand showing presence of some oxidized and carbonized oil on some grains.

such as those given to youngsters as Christmas presents could be used, although instruments can be purchased for a few dollars more at medical school equipment houses, pawnbrokers and secondhand stores, with far better results and greater satisfaction in both visual inspection and photomicrography. A simple compound microscope, which can be purchased secondhand (with 1-2 objective lenses and eyepieces) for perhaps $100, is entirely satisfactory if the purchaser is willing to forego such conveniences as a mechanical stage, substage filter glass carrier, turret-type objective nosepiece, and sacrifice a little insofar as the flatness of the field is concerned.

Simple Equipment Sufficient. Most work on foundry sands is done at less than 50 diameter magnification and will require a 32 or 48 millimeter objective lens and perhaps 5×, 7.5× and 10× eyepieces. These combinations will give magnifications up to 50 diameters and, for most purposes in foundry sand study, will be ample. The author does not wish to convey the idea that the least expensive equipment should be purchased, but it is foolish to buy equipment such as is required when doing work at 500 or 1000 diameters or higher. Any reputable optical equipment dealer can and will help in the selection of the appropriate equipment. If $500 or more has been allotted for photomicrographic equipment, by all means buy the best, as the only criteria of what to buy are (a) will it do the job required and (b) does it fit the budget?

How a Microscope Works. The compound microscope, as it is termed in textbooks on optics, consists essentially of two parts, the objective lens and the eyepiece. As illustrated in Fig. 1, the objective lens (the lens on the lower end of the body tube) will form a real but inverted image of the object being examined at plane 1 in plane 2, but the field lens of the eyepiece intercepts the rays forming the image on plane 3. The image is examined with the eye lens, which acts as a magnifier forming a virtual image at plane 4. Thus the object undergoes two stages of magnification—first by the objective lens and the second by the eyepiece. Therefore, the magnifying power of the microscope is the product of the power of magnification of the objective lens times the magnifying power of the eyepiece.

Magnifying Power of Objective × *Magnifying Power of Eyepiece* = *Magnifying Power of Microscope*

At this point one might be led to believe that by making the eyepiece high enough in magnifying power an unlimited degree of magnification might be obtained, but this is not true and would lead to complications. The basic reasons underlying this failure are due to the structure of the objective lens and of light itself. However, since the microscopic study of sand is carried out at low magnification, these difficulties encountered in high magnification work will not be discussed here.

Microscope Parts. Our microscope consists of the following easily identified parts: foot piece and supports, arm, body tube, draw tube, stage, eyepiece and objective, fine and coarse adjustment knobs and rack

Assuming that the best microscope that the budget will permit has been obtained, the operator now is ready to put it to use in the examination of foundry sands. Perhaps the microscope has a mirror and substage condensor. These are useful in the examination of materials that are transparent or nearly so, in which case the light rays from a light source can be caught by the mirror, "squeezed" or condensed to a small beam by means of the substage condensor and passed through the specimen as a concentrated brilliant light. This, however, is not so with foundry sand which ranges from a dense black crystal to a milky or almost transparent color. For the present, let us forget the mirror and substage condensor, and swing it over to the side until such time as it is needed. Now to begin work.

Preparation of Sample and Focusing. Obtain a sample of new sand

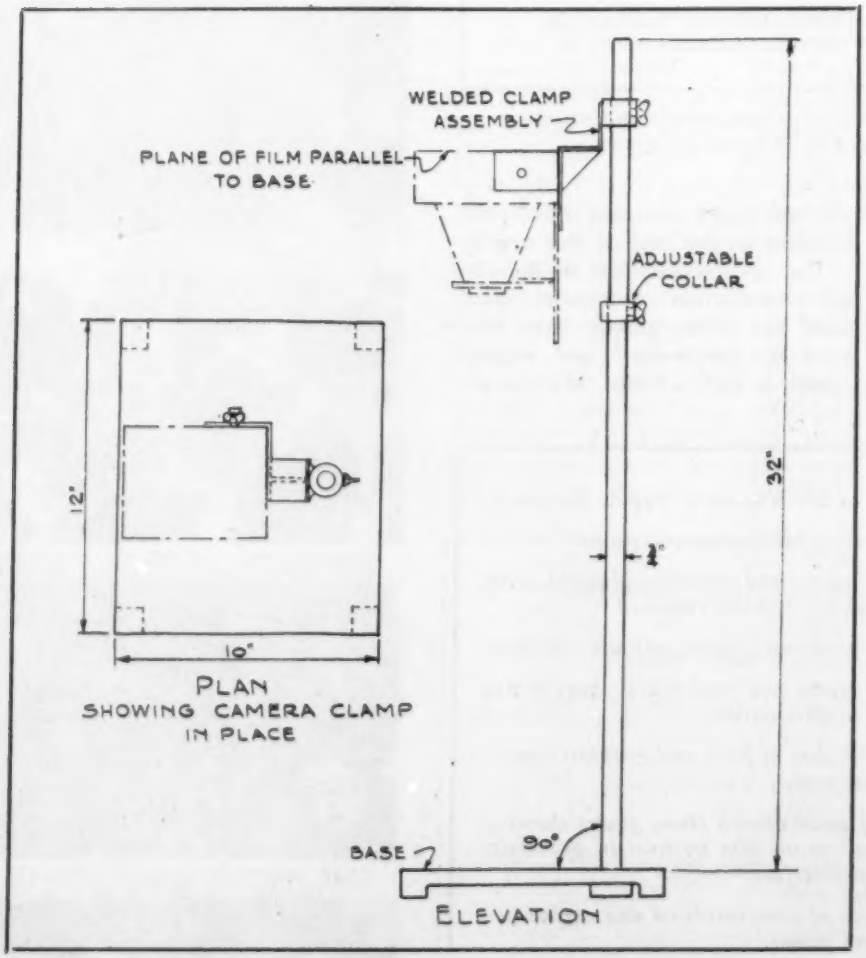


Fig. 2—Sketch of base and stand for microscope and camera.

(a pinch will do) and spread it evenly with a spatula over the surface of a glass microscope slide and place the slide on the stage. Tap the slide gently to arrange the grains in a layer "one-grain" thick. (Use the microscope near a window to get sufficient light, or place a desk light near the stage to obtain the desired degree of illumination.) Use a 5× eyepiece and 32 mm. objective lens in the microscope, pull out the draw tube to the length recommended by the manufacturer (usually 160 mm.) and turn the coarse adjustment until the objective lens is somewhere near 1¾-in. from the specimen. Carefully raise or lower the body tube of the microscope by the adjustment knobs until the object is in focus.

If the variation in size of the sand grains is not too great, it should be possible to get almost all of the grains in sharp focus. If it is not possible to get most of the grains in focus, too high a magnifier in the eyepiece or in the objective lens is being used. In the visual observation of any object when the magnification is raised, these basic conditions and limitations must be kept in mind: (a) the working distance between specimen and objective lens is decreased; (b) the depth of focus is decreased (that is, the depth at which the entire object will be in sharp focus); (c) the size of the field which can be observed is decreased. These limitations, in general, are not met in working with magnifications up to approximately 30 diameters, but offer special problems in illumination and technique in observation and photography when working at higher magnifications.

Appearance of Sand Grains. Now that the sand grains are in focus, what is seen? The red splotch on that white sand grain is probably a dab of clay or iron oxide. The light brown grain is probably a silica grain stained through and through with iron, much as glass is colored and stained by impurities present. Notice the surface of the grains. They are not smooth like marbles and not perfectly round as the observer might have imagined them to be. Note also that some grains have cracks and fissures in them. Those grains probably will break down into dust on being used a couple of times in contact with hot metal or may break in mulling or handling by the sand conveying system or sand slinger.

Look at a sample of used core sand from the core knockout or a sample from the molding sand heap. A considerable change from what the new sand looked like is noted. Some grains are almost pure black, others are colored a dark brown, some have a spongy coating of burned clay or cereal binder on them, and still others are almost like new. The observer probably will find a considerable portion of very minute particles present, some of which sparkle like gems while others do not. The shiny particles probably are fine particles of silica that have been broken down from larger grains that were inherently weak; the dull particles are probably particles of sea coal, clay, burned-out pitch or other organic matter. The black grains from the core knockout probably are covered with carbon from the carbonized oil, the dark brown grains are oxidized oil coatings that have not been as completely carbonized.

Microscope Helps to Solve Sand Problem. Here is the beginning of a fascinating and instructive field of study! Here is a new tool with which to study any number of sand problems! It will help to answer such questions as: "How well does the sand we use stand up under usage?; how well does the mixer recondition the sand?; are we thoroughly mixing our ingredients?; are we completely covering our sand grains with the clay that we are adding, or are we just putting big splotches of clay unevenly through our sand?; is our sand really 'burning-on' to the castings or is our sand so open that we are getting metal penetration?" These questions and many others can be answered by the use of the microscope and a permanent record made of the findings for future reference. The interpretation of what has been observed in using the microscope is not difficult and the more the equipment is used, the more rapidly can the observer interpretrate what he sees.

Illumination

Once the thrill of the first few sand examinations has worn off, the observer is ready to consider seriously his sand investigations and, as an outcome of this, he will desire, in all probability, to record photographically what he has observed through the microscope.

There are many days when there is insufficient light coming from a nearby window to make visual observation and photography entirely satisfactory. To eliminate the variations in light on bright and cloudy days, lighting should be standardized. If the observer used a desk lamp in his initial trial with the microscope, he was on the right path to controlled illumination. The author has found it highly satisfactory to emply two desks lamps of the gooseneck type (one on each side of the microscope) to illuminate the specimen under observation. Two 100-watt bulbs, either of the daylight or frosted type, are used for visual observation or for "black and white" photography. The same setup is used for color photography with Kodachrome film, but the 100-watt bulbs are replaced with No. 1 photoflood lamps which yield light of sufficient intensity for this work (light temperature emitted from the No. 1 photoflood lamps is approximately 3300° Kelvin or 3027° C. or 5480.6° F.).

Construction of Photographic Unit. To make a sturdy, compact unit to handle both visual and photographic work, it is advisable to construct a unit such as shown in Fig. 2. The base upon which the microscope rests is a gray iron casting 10 in. by 12 in. and machined to a smooth flat surface, drilled and tapped to accommodate the perpendicular upright support (used for holding the camera above the eyepiece of the microscope when photomicrographs are being made). The upright support must be absolutely perpendicular to the base upon which the microscope rests and the camera support made perpendicular to the upright support. This, simply expressed, means that the plane of the film used in the camera must be parallel to the plane of the microscope stage, or any pictures taken will be distorted. When the camera is not being used, it can be swung out of the way and will not interfere with visual examination.

The lights used for illumination of the specimen need not be an integral part of the camera-microscope stand and can, therefore, be adjusted to give the most satisfactory illumination for any particular study. The microscope and camera stand, when

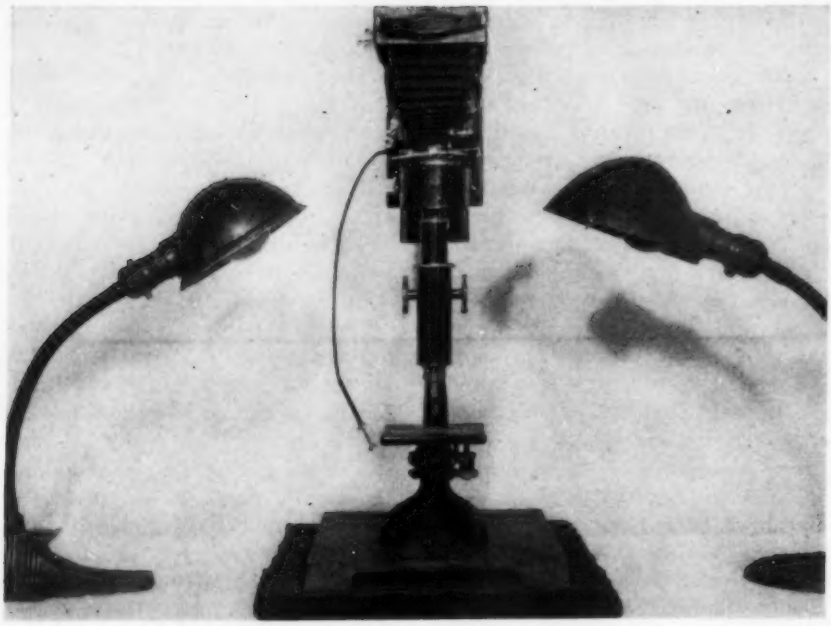


Fig. 3—Photomicrographic set-up showing placement of camera, lights, and microscope. Unit ready for exposure.

constructed as mentioned, then is placed on sponge rubber. This is a precaution against vibration of the unit by local disturbances. Using such a precaution, if the unit is affected by vibrations it will vibrate as a unit.

The Camera

If the reader is not interested in photographically recording what he has observed through the use of the microscope in the study of foundry sand, the following perhaps will be of little interest to him.

In the choice of cameras for photomicrography of foundry sands, there is as much choice as there is in the selection of a suitable microscope for visual examination. At this point, it may be well to state that the simplest camera to use is in reality not a camera at all as a camera lens is not required. In reality, it is a light-tight box at one end of which there is a shutter to admit light at will and at the other end provision is made for placing a piece of ground glass or photographic film. The author experimented a great deal with various cameras, finally coming to the conclusion that all that is necessary for satisfactory results is the aforementioned arrangement.

A folding camera, having either single or double extension bellows, equipped with a ground glass back and plate holders or film pack adapter is a very satisfactory arrangement. *No lens is required* as the eyepiece lens of the microscope is used as a projection lens, projecting the image onto the ground glass or film. Cameras of this type are not difficult to find and, since no lens is required, can be purchased for considerably less than the price paid by many amateur photographers using these cameras for general photographic art.

The author uses a Kodak Recomar No. 33 camera in his setup, which was equipped with a F 4.5 anastigmatic lens, film pack adapter, three cut film holders and cable shutter release, and purchased for the sum of $45. Such a camera is most useful. When it is needed for shop pictures of equipment, experimental setups, etc., the lenses are inserted and the required pictures made; when it is required for photomicrographic work, it can be adapted quickly to that field of work by simply removing the lenses. If one wishes to spend considerably more than this for a camera, the Leitz, Zeiss, Spencer, and Bausch & Lomb companies all have equipment to suit the taste and purse. Complete photomicrographic equipment units also can be obtained from these companies. However, large, expensive photographic units are outside the scope of this paper, which is written specifically for individuals and companies which have a limited amount of money to spend.

Photomicrography

The word "photomicrograph" is composed of the two words "photo"

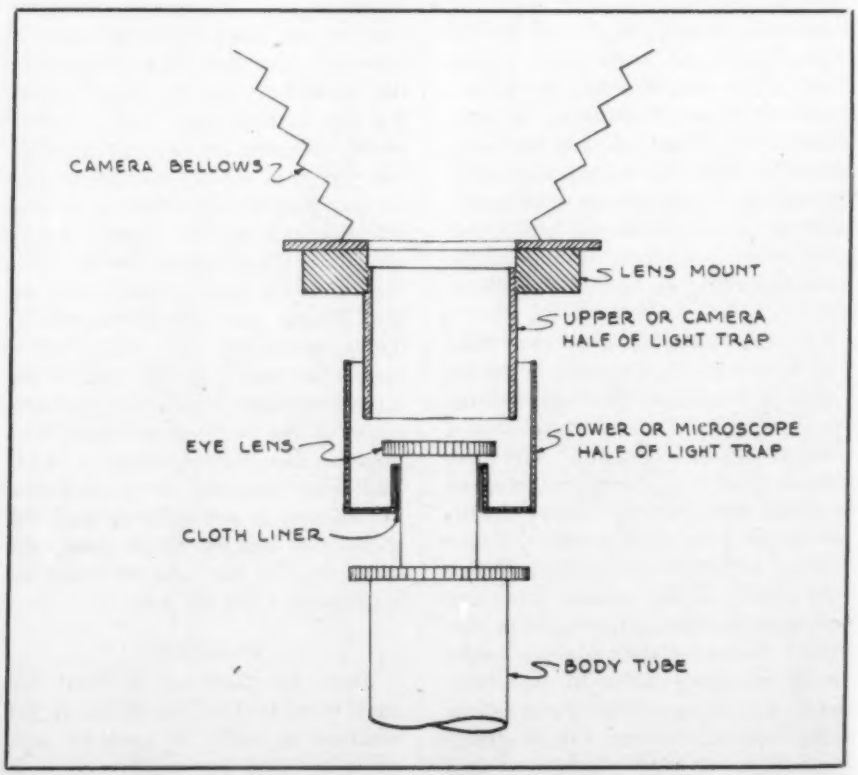
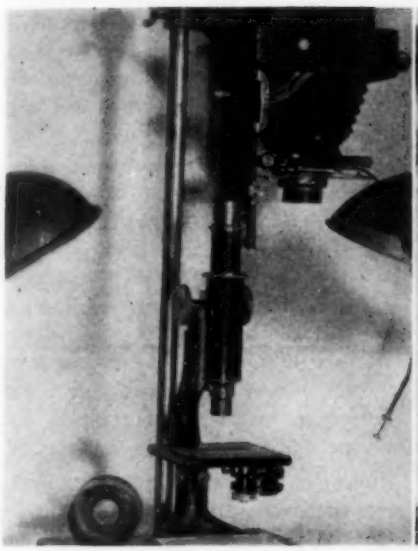


Fig. 4—Sectional view of light trap.



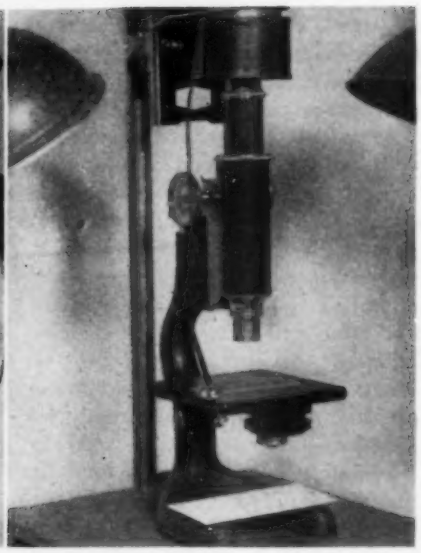


Fig. 5 (left)—Photomicrographic set-up showing camera moved to side for visual observation of specimen. Microscope half of light trap placed on base plate of stand. Fig. 6 (right)—Side view of photomicrographic set-up with camera in place and light trap in operating position ready for exposure.

or "photograph" and "micrograph." A "photograph" is a picture produced by exposing a plate or film, sensitized or coated with certain chemicals, to the action of light. A "micrograph" is an enlarged reproduction of a minute object and usually made free hand or by using a pantograph. If, however, an enlarged reproduction of a minute object is obtained photographically, the result is termed a photomicrograph.

At this point, we shall assume that everyone reading this article has at some time or another used a camera of some sort and has taken a photograph or picture and noted that light and film were required. The camera lens brought the subject to be photographed into sharp focus and with the opening of the shutter allowed the light to pass through the lens and strike the film. The film then was removed and developed to bring out the latent image produced by the action of light on the sensitized film. The film, after development and fixing, then becomes a negative. The negative is, in its simplest form, a picture in which right and left and light and shade are the reverse of those in the original subject photographed. The negative then is used to produce a positive by passing light through it. The light passes through the light portions of the negative striking a sensitized surface, the amount of light allowed to pass being dependent upon the density of the negative. The surface so exposed is then developed and fixed chemically to produce the positive which is commonly known as a picture or photograph.

A knowledge of photography is a great help in photomicrography and, needless to say, helpful if the photographer wishes to do his own developing, printing and enlarging. However, it is not absolutely necessary that the photographer have knowledge of those operations as the exposed film can be taken to a photo finisher or the "corner drugstore" and positive prints made from the film and returned to him in a manner similar to our "week-end picnic" pictures. However, the subject is so fascinating that most readers will wish to do their own work, thereby adding to the enjoyment obtained in photomicrography. For those who have little or no knowledge of the photographic art, a list of excellent books on the subject, which the author has found most instructive and helpful, will be found at the end of this article. Perhaps the shop "camera-bug" (every shop has one) can be called in by the novice photomicrographer with mutual aid, interest and benefit to all concerned.

Photomicrographic Technique

Perhaps the simplest means (although not the best) of acquainting the novice with the technique of photomicrography, is to illustrate the method used by the author, which is quite satisfactory. Realizing that most people become proficient more rapidly by the knowledge derived from others, the technique offered here has given, to date, most satisfactory results.

The setup for lights, camera and microscope is shown in Fig. 3, with the distances as indicated. The microscope rests firmly on the machined gray iron plate with the stage of the microscope parallel to the base. The iron base itself rests upon a sheet of sponge rubber to absorb undesirable vibrations. The microscope slide with the sand sample is placed on the stage, the lights turned on and a preliminary visual observation made for the most desirable field. The bottom half of the light trap (shown in Fig. 4) then is placed on the draw tube by first removing the eyepiece and then replacing same after the light trap has been placed on the draw tube (Figs. 5 and 6). The camera with the upper half of the light trap is now swung into place directly above the microscope eyepiece and locked into place by a wingnut. The camera bellows is lowered to a point where the upper and lower halves of the light trap fit well into each other but do not touch. The camera shutter then is opened and, with the ground glass in place, is ready for final focusing.

Final focusing is accomplished by focusing the microscope so that a sharp image is formed on the ground glass. A black cloth over the head of the observer and hanging well over the sides of the camera back will assist appreciably in obtaining sharp focus at this point. A hand magnifier or reading glass will also assist the observer at this point. When sharp focus has been obtained, the camera shutter is closed and the ground glass replaced with the film plate holder or film pack adapter. The exposure is now made. As a start, the photographer might try 15 sec. To find the correct exposure for certain types of sand, it is well to make the "strip exposure" test in which sections of a single film or plate are exposed for varying lengths of time by withdrawing the film or plate holder protective sheath a portion at a time. The correct exposure by this method can

easily be found. Relative to what film to use in photomicrography, a film of medium speed, such as Verichrome, Panatomic X, Process Ortho, etc., is very satisfactory. Figures 7 and 8 show the results obtained using this technique and also the appearance of various sands under the microscope.

The exposed film or plate is now developed and fixed in the usual way. Any film developer, such as Eastman's 76 for developing, followed by a clear water rinse or short stop bath, and fixed in standard sodium thiosulfate (hypo) can be used. The processed films are dried and labeled and contact prints or enlargements made as required.

Color Photography. After the novice has obtained a degree of proficiency in taking "black and white" photographs, he will, no doubt, wish to try his hand at color photography. The technique for this type of work is identical to that for "black and white" with the exception that the 100-watt lamps are replaced with No. 1 photoflood lamps for illumination and exposures of 30-35 sec. are made. Color-compensating filters may be required, due to the light absorption of certain wave lengths by the optical system of the microscope.

Light Wave Absorption

The author has found Eastman's CC-14 CC-15 filters helpful in overcoming light wave absorption by the microscope optical system. These filters are dyed gelatin filters approximately 2 x 2 in. and can be obtained mounted in optical glass or unmounted. The author uses unmounted filters which are cut from the squares into ½ x ½-in. pieces and placed directly over and on the eyepiece lens of the microscope. To prevent "finger-marking" the filters, a pair of tweezers is used for placing and removing the ½-in. squares.

Kodachrome film can be obtained in several roll film and professional cut film sizes. As Kodachrome in the larger sizes is comparatively costly, the author uses a Recomar Kodachrome adapter, which accommodates bantam size Kodachrome film.

This arrangement is neat and economical, as the individual exposures cost no more than a package of cigarettes. The exposed film is mailed to the Eastman Company and processed (the cost of the film includes this processing) and returned to the user mounted in individual 2 x 2-in. mounts ready for slide projection or for a viewer. The transparencies also can be used for making positive prints in several sizes, when taken to the Eastman Company to be processed by them.

Photomicrographers, who are interested in color photography, should find a world of information in "The Data Book on Color Photography with Kodachrome," published by the Eastman Kodak Co., Rochester, N. Y. In passing, it may be said that sand pictures in color tend to overcome one of the short-comings of "black and white" pictures in that not only are the sand grains seen in the same colors as the eye sees them, but a definite "third dimensional effect" is imparted to the picture. However, the "third dimension" unfortunately can be obtained only by a binocular type or stereoscopic type of microscope and camera when taking "black and whites."

Much can be written on the subject of photomicrography in regard to both technique and equipment. Such a discussion would lead only to lengthy dissertations on the merits and disadvantages of particular pieces of equipment and methods.

Conclusion

The author's studies of foundry sands base impressed upon him the simplicity and ease with which both visual and photographic studies can be made. He has resisted arguments concerning equipment and procedure and has produced entirely satisfactory results with a very modest initial investment.

It is sincerely hoped that many foundries that do not now possess a microscope or camera will feel a desire to explore the possibilities of using these tools in their everyday foundry practice, thereby adding immeasurably to the existing knowledge of one of the most widely used, yet perhaps least understood, basic materials in metal casting—sand.

The author wishes to thank the following persons and organizations for the cooperation and aid extended in the development of his present photomicrographic technique and in the preparation of this paper:

Miss C. Dupuy, C. H. Krause (U.S.N.), and R. E. Wick, Sand Research Laboratory, Hydro-Blast Corp., Chicago, and W. E. Smith, Eastman Kodak Co., Rochester, N. Y.

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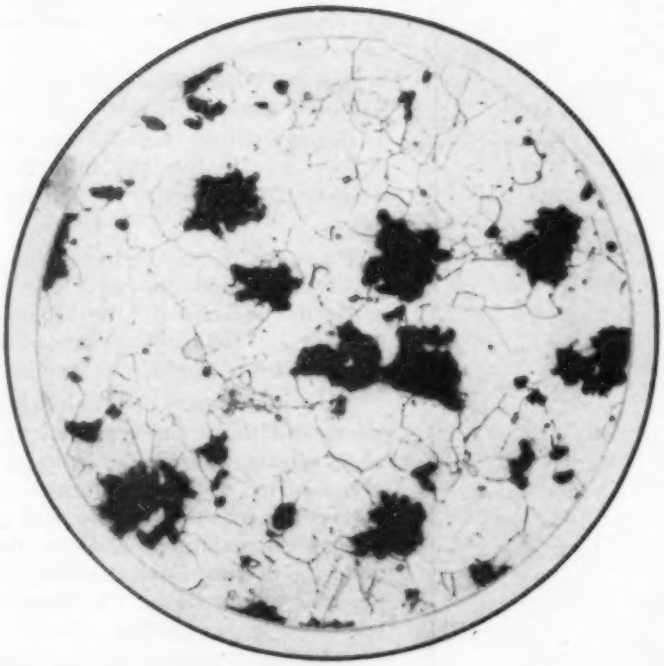


Plate I—Photomicrograph showing ferrite and temper carbon structure of normally annealed malleable cast iron. Unetched.

• The particular product dealt with in this discussion is malleable iron castings. The control processes deal with melting the cold charge in powdered coal fired reverberatory furnaces and annealing the castings in periodic ovens. Many of the control principles discussed could be applied to other melting and annealing processes.

MALLEABLE IRON CONTROL

By M. E. McKinney,
Chief Metallurgist, International Harvester Co.,
Hamilton, Ont., Canada

THE control of manufacturing processes is an interesting and attractive study, probably because therein perfection is attempted but never attained. There always remains this or that variable from which, although it might be controlled, the added benefits are not worth the expense entailed. Usually, however, if a few of the most dangerous variables are controlled the sum total of the remainder will not cause the finished product to vary outside those limits necessary and acceptable in a good commercial product.

Control in General

The object of control in malleable castings is to turn out a product which will give entire satisfaction both in subsequent manufacturing operations and in service. As it is extremely difficult to apply any suitable test to numerous different shapes and sizes of castings, quality of the metal itself usually is based on a test bar, the physical properties of which have been set by most of the leading metallurgical and mechanical societies.

Complaints from the shop and from the field of service usually are caused by that part of the product which falls below standards in physical properties. The questionable advantages of any part of the product which is above standards can never offset the complaints caused by that part below standards. The object of control is to eliminate that part of the product which falls below standards.

Before attempting control one must be aware of all the variables which might affect quality. One must also have a fair knowledge of their relative importance. Control then should be started on those variables of greatest importance, and continued until that part of the product falling below standards has been eliminated. The value of any further control is doubtful unless, of course, some reduction in cost is accomplished which will pay for the added control.

Malleable casting production can be divided into three main headings; raw materials and mixtures, melting practice, and annealing. Control must be applied to each of these three.

Now control to some people means an apparatus of some kind, usually automatic, which when attached to a furnace or oven immediately becomes a panacea for all ills, and from thence on all troubles cease. Such persons are doomed to quite rapid disappointment.

Some methods of control are much more complicated than an automatic apparatus, but the greater part are really much simpler. A large part of control entails no apparatus at all, but simply the application of some rule or habit of good sense and order.

Psychological Factors

Psychology plays a very important role in control, especially where some piece of apparatus must be put into the hands of an already experienced and reasonably successful operator. A few of the psychological factors are as follows:

Let the operator know that he is being provided with a new tool which he will not be able to use until he has mastered its principles.

Let him know that any Tom, Dick or Harry would not have the furnace knowledge necessary to learn how to use it and appreciate its advantages.

Let him know that when he has learned how to use it he will be still more experienced than he now is, and that if he can master it his work will become manually easier.

It is always an advantage to have the commendation and

Table 1

MELTING LOSSES

Date	Silicon Lost*, Per Cent: Before Prelim. Analysis (1) Daily	(2) 5-Day Avg.	After Prelim. Analysis (3) Daily	(4) 5-Day Avg.	Carbon Lost*, Per Cent: Before Prelim. Analysis (5) Daily	(6) 5-Day Avg.	After Prelim. Analysis (7) Daily	(8) 5-Day Avg.
Nov., 1943								
1	(0.49)	.....	(0.13)	.....	(0.47)	.....	0.20	.....
2	0.27	.....	(0.09)	.....	0.29	.....	0.24	.....
3	0.29	.....	0.03+	.....	0.34	.....	(0.27)	.....
4	(0.39)	.....	0.04+	.....	(0.39)	.....	0.14	.....
5	(0.30)	.....	0.00	.....	(0.36)	.....	0.18	.....
6	0.18	0.286	0.01+	0.002	0.23	0.322	0.24	0.200
8	0.24	0.256	(0.06)	0.004+	0.33	0.310	(0.26)	0.212
9	0.25	0.252	0.02	0.012+	(0.33)	0.318	0.23	0.210
10	(0.29)	0.252	0.03+	0.012+	0.29	0.308	0.25	0.208
11	0.27	0.246	0.04+	0.012+	0.25	0.286	(0.28)	0.232
12	0.28	0.244	0.00	0.012+	0.26	0.272	0.24	0.244

*Plus marks indicate a gain instead of a loss.

Table 2

LOSS CALCULATION

Date: Nov. 12, 1943. *Heat No. 1, Furnace No. 1*

	Per Cent Si	Per Cent C
Calculated Analysis	1.25	3.00
Preliminary Analysis	0.97	2.74
Loss Before Preliminary	0.28	0.26
Preliminary Analysis	0.97	2.74
Added Elements	0.05	0.00
Rectified Preliminary	1.02	2.74
Final Analysis	1.02	2.50
Loss After Preliminary	0.00	0.24
Avg. Loss Before Preliminary	0.244	0.272
Avg. Loss After Preliminary	0.012	0.244
Avg. Total Loss After Preliminary	0.232	0.516
Desired Final Analysis	1.000	2.500
Required Calculated Analysis	1.232	3.016

praise of the apparatus come first from the operator himself.

Do not create the impression that with this apparatus his experience and skill are no longer necessary.

Do not create the impression that from now on, any Tom, Dick or Harry can operate the furnace, and the results will be even better than before.

Do not create the impression that the apparatus knows more than the operator does about what is going on inside the furnace. If this is so, the operator will find it out for himself.

Any control or apparatus must be good enough to sell itself or it is doomed to failure.

Raw Materials and Mixtures

Control must start right at the stock piles of pig iron and scrap. The manner in which a charge melts down and changes in composition is affected by the physical structure, size and shape of pig iron and scrap as well as by their chemical analysis.

Two heats of pig iron of identical analysis may not lose silicon and carbon to the same extent. Heavy scrap will not melt down with the same losses in chemical elements as light and thin scrap. This applies to steel scrap as well as to malleable scrap.

Since physical structure, size and shape are not controlled, their effect must be controlled by averaging out these variables. This control is exercised by following a few simple rules and principles.

Cars of pig iron are sampled by selecting one pig for every 5 tons. If pigs of different aspects are remarked in the car, a representative number of each kind are selected. Equal weights of drillings from each pig are mixed to form the sample for analysis of the car.

Cars of pig iron are unloaded and spread out to even thickness, one car on top of another to form piles as large as is practicable. When using from these "layer cake" piles, pig iron is loaded onto the charging barrows by taking from the face of the pile. In this way any differences due to physical structure or size are averaged out.

Piles are made up of cars that do not vary more than 0.50 per cent in silicon content, and the average analysis is calculated by using the weights and analyses of the individual cars.

Before one pile of pig iron is completely consumed, the next pile is gradually worked into the mixture so that a change is not made abruptly from one pile to another.

Analysis of bought malleable scrap always will be a problem, but analyses of samples from the scrap pile over a period of time will furnish an average analysis that can be used in making up mixtures and, as the quantity of this rarely exceeds 15 per cent of the mixture, it becomes one of the lesser variables.

More important is the size and shape of this scrap, which should be loaded and charged in such a manner that each heat receives the same proportion of heavy and light scrap. The same remarks apply to the steel scrap used in the mixture.

Judicious segregation of foundry returns will give a supply of this material of known analysis and regular size distribution. The amount of annealed returns usually is so small that this may be grouped with the unannealed returns at the same analysis.

Mixture Calculation

If it were known exactly how much silicon, carbon and manganese would be burned out during the melting of a heat, the problem of mixture calculation would be a simple one. However, fact is not of the future, so these losses must be estimated.

Usually, manganese will take care of itself. Assuming that the loss of silicon and carbon will be the same as in any *one* previous heat would only be guessing or estimating with insufficient data.

In this particular foundry, practice has shown that the best pro-

This paper was secured as part of the Program for the 1945 "Year-'Round Foundry Congress" and is sponsored by the Malleable Division of A.F.A.

cedure is to consider the last six heats, eliminate the highest loss found on each element and use the average of the remaining five figures as the estimated loss for the next heat. This principle is used for the drop in carbon and silicon from preliminary to tapping, as well as from calculated analysis to final heat analysis.

Tables 1 to 5 are excerpts from the records of this data, and are used in calculating the mixture for one particular heat. The mixture is calculated just as soon as the final analysis of the previous heat has been finished.

Forms

Table 2 shows the form that is used in calculating the losses for the last heat melted and in estimating the losses for the next heat. Table 1 is a sort of running inventory of silicon and carbon losses used to calculate the average loss figures used on the form in Table 2.

The difference between the calculated analysis and the preliminary analysis (0.28 per cent silicon and 0.26 per cent carbon in this case) is carried over into columns 1 and 5 on the loss sheet. Any additions after the preliminary then are added in (0.05 per cent silicon in this case), and the difference between this and the final heat analysis calculated (0.00 per cent silicon and 0.24 per cent carbon in this case), and these figures carried over into columns 3 and 7 on the loss sheet.

Averages

Then, considering the last 6 days only, the maximum figures are eliminated (those in parentheses) and the averages made of the other five in each column. These averages then are carried back onto the loss calculation form and totaled. This total is added to the desired final analysis to give the required calculated analysis for the next heat.

Table 3 shows the mixture calculation sheet, which is almost self-explanatory. Now if the loss on this heat is the same as the average over the last 6 days, this heat will require no additions and will show exactly the desired analysis at the finish. It does not always happen exactly this way but, since our estimate is halfway between the extremes, if an addition is necessary it will be only a small one.

Tables 4 and 5 show the front and back of the form sent to the foundry weigh scales in duplicate. As sent from the laboratory, only the columns "Material" and "Per cent" are filled in along with the calculated analysis. All of the other figures on both sides are filled in by the foundry and one copy returned to the laboratory.

The foregoing is a brief outline of the method followed in calculating the mixture. The only training necessary is in ordinary arithmetic. It is based on nothing more than the law of averages; it has a definite formula and has nothing whatsoever to do with metallurgy. Any bright grammar school graduate can do it just as well as an experienced metallurgist.

Melting Control

The foregoing method of mixture calculation is based on the premise that all of the details of charging and melting practice will be such that the loss in silicon and carbon on any one day will be within the

Table 3

MIXTURE CALCULATION

Date: Nov. 13, 1943. Heat No. 1, Furnace No. 1

			Mixture					
Charging Material.		*Per Cent*	*Si*	*Mn*	*C*	*Si*	*Mn*	*C*
Pig Iron	Car No. A	19	1.40	0.80	4.05	0.266	0.152	0.770
	Car No. E	6	2.15	0.75	3.90	0.129	0.045	0.234
	Car No. D	21	1.35	0.85	4.10	0.284	0.179	0.861
	Special Sprue	10	1.70	0.45	2.40	0.170	0.045	0.240
Domestic Scrap		30	1.00	0.38	2.50	0.300	0.114	0.750
Bought Mall. Scrap		7	0.90	0.30	2.00	0.063	0.021	0.140
Steel Scrap		7	0.20	0.40	0.20	0.014	0.028	0.014
Calculated Analysis			....	....	....	1.226	0.584	3.009

Table 4

MIXTURE

MALLEABLE FOUNDRY

Date: Nov. 13, 1943. Heat No. 1, Furnace No. 1

Material		*Per cent*	*Weight, Lb.*
Pig Iron	Car No. A	19	6155
	Car No. E	6	1980
	Car No. D	21	7045
	Special Sprue	10	3300
Domestic Scrap		30	9900
Bought Mall. Scrap		7	2310
Steel Scrap		7	2310

Cal. Analysis.....Si—1.23.....C—3.01.....

Weight of Charge.....33,000 .....Started Firing.....4:00 A.M. .....
Started Slagging.....8:20 A.M. .....Preliminary Test .....9:25 A.M. .....
Loads of Slag.....9 .....Additions Made .....10:10 A.M. .....
Started Tapping..... 10:35 A.M. .....Finished Tapping.....11:15 A.M. .....

.....
Signature

Table 5

FIRING SCHEDULE

Time	*Ratio Coal to Air*
4:00 A.M.	10:6
4:20	11:8
4:40	12:10
5:00	14:12
5:20	15:13

Additions

.....99.....lb. 50% Ferrosilicon
.....lb. Petroleum Coke
.....lb. Manganese Pig
.....lb. Steel Scrap

(Tables 1 to 5 and Figs. 1-5 are reprinted from a paper "Malleable Mixture Calculation and Melting Control" presented by the author at the 48th Annual Meeting of A.F.A., Buffalo, N. Y., April 26, 1944, and published in A.F.A. Transactions, vol. 52, pp. 441-458, 1944.)

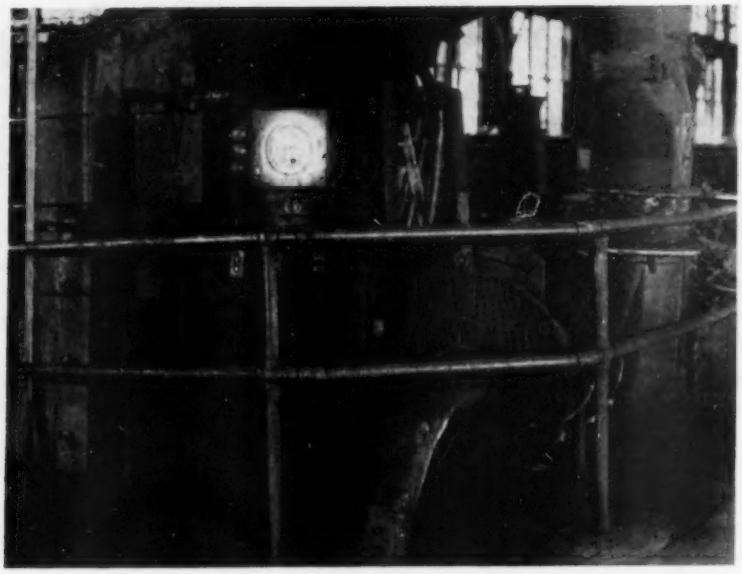


Fig. 1—Burner end of melting furnace and control board for coal- and air-feeding.

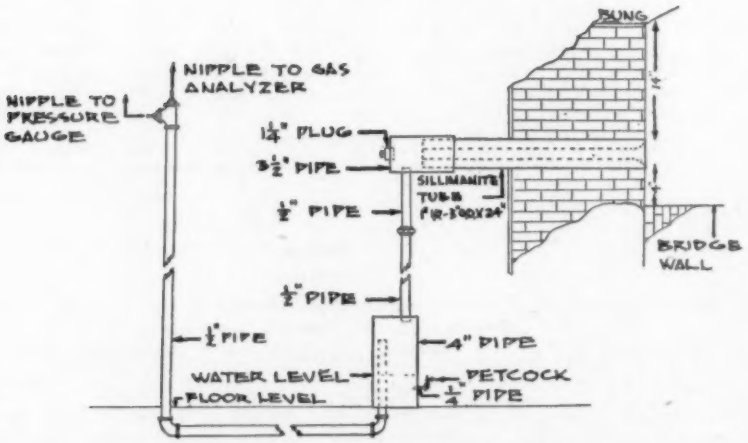


Fig. 2—Exit gas line from furnace to instruments.

range of practice prevailing over the previous 6 days, the highest loss figures excepted.

These details of practice include the charging of the furnace or the location of pig iron, foundry returns, bought scrap and steel scrap. Bought scrap and steel scrap must be in the same proportion of heavy to light from one day to another. The heat must be worked in the same manner every day as regards poling or barring up.

Fuel-Air Ratio

One of the main factors of melting control is the fuel-air ratio or CO-CO_2 balance over the charge while melting down and while superheating. The same blower gate setting and coal feed screw setting will not always give the same CO-CO_2 balance. And even the most experienced melters cannot always visually estimate this balance from flame aspects.

Figure 1 shows the burner end of the furnace. Powdered coal is blown to the furnace from a central pulverizing station. The supply of coal is regulated by a remote control and an indicator of the speed of the feed screw at the pulverizer. A constant quantity of primary air is furnished by a fan type blower at the pulverizer and blows the coal to the melting furnace, where it enters at the center of the shutter type gate used to control the secondary air.

Analysis of exit gases will furnish indications much more accurate than visual estimation as to the CO-CO_2 balance existing in the furnace. Sampling must be done far enough away from the burners so as to guarantee that reaction is complete. The furnace also must be operated under slight pressure so that infiltration of air through doors or other openings will not falsify gas analysis indications.

Incidentally, slight furnace pressure has been found to give the best melting conditions. Therefore, it is evident that furnace pressure must be controlled to ensure a gas sample representative of firing conditions at the burner, and that some gas analyzer must be used which will eliminate the personal element as completely as possible.

Gas Sampling

For sampling, the simplest and most foolproof combination found to date is shown in Fig. 2—a thick ceramic sampling tube built into the wall of the furnace, a piece of large diameter pipe at the outlet end, a trap with a water seal and ordinary gas pipe to the two instruments.

This set-up, installed with the two instruments, is shown in Fig. 3. The outlet from the furnace, the trap, the petcock for checking the water level, the tube going underground, nipples and rubber connections to the pressure gage and the gas analyzer.

Instruments

Figure 4 is a close-up view of the instruments. At the left, a typical boiler draft gage, each small division representing 0.02-in. draft or pressure. At the right, a gas analyzer of the thermal conductivity type, such as is used to regulate carburetors on motor cars. The original calibration of lean, normal, and rich has been changed to conform to the best air furnace practice.

Furnace Operation

At the start of firing and until pressure is built up in the furnace, the analyzer is inoperative. During this period some predetermined schedule of fuel and air feed must be used. As soon as enough pressure is built up, the gas analyzer starts to operate. From this time on the coal feed is regulated according to the indications of the analyzer. The air setting is left to the judgment of the melter, who may vary the intensity of firing by this means.

A preliminary sample is taken at

the usual point in the melting of the heat and sent to the laboratory for analysis. This is analyzed in about 20 min. and the foundry notified on three points:

1. The analysis results.
2. The corrective additions if necessary.
3. The firing method until tapping out.

Addition Computator

The last two indications are read off directly from an "addition computator" (Fig. 5).

On this computator there are two movable slides. One represents the silicon analysis of the preliminary sample, and the other the carbon analysis. The smaller figures on the outside represent the average loss after preliminary sample over the previous 6 days, and which figures are set opposite the shaded rectangles.

The slides in the positions shown indicate a 10-point drop in silicon and a 20-point drop in carbon. With the preliminary analysis at hand, one particular square on the central chart is designated. The position of this square and the figures or lack of figures in it, indicate the quantity of additions and the firing method.

Annealing Control

The annealing ovens used in this foundry are of the old periodic type, powdered coal fired. Only two pyrometer couples are installed, one at the bottom rear or burner end, and one at the opposite end about halfway up from the bottom. The ovens are fired on the indications of these couples, but since they indicate only furnace temperatures (not inside pot temperatures) and do not show the conditions in the extreme corners, more definite means of control are necessary.

Extra test bars are cast with each heat, and from these are built up a stock all within narrow and normal analyses. From this stock of test bars, 10 are annealed in each oven, these being packed at all of the extreme points. The positions are top and bottom pots in each of the four corners, and top and bottom in the center.

These bars are each given a bend test, a Brinell hardness test, and then examined under the microscope for

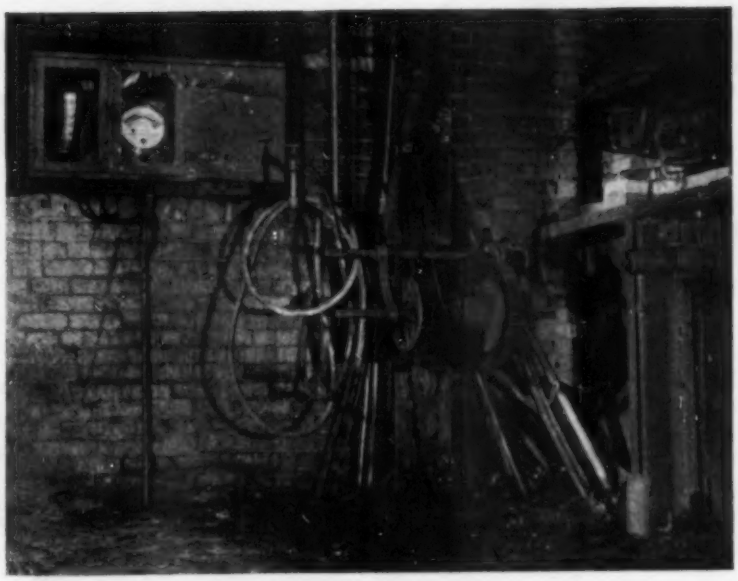


Fig. 3—Gas sampling tube and recording instruments.

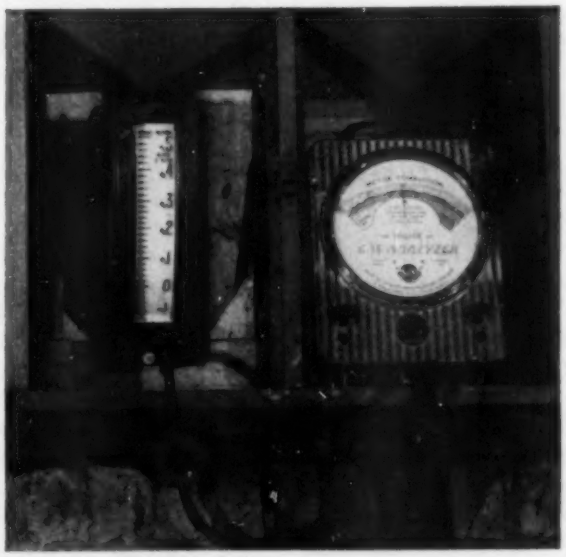


Fig. 4—Close-up of draft-pressure gage and gas analyzer.

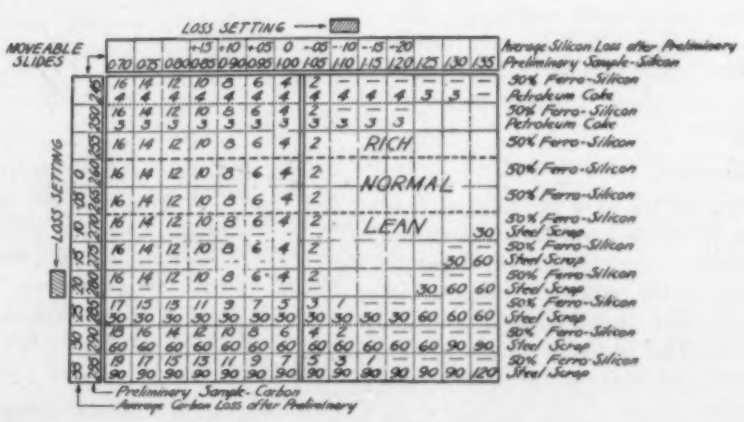


Fig. 5—Addition computator.

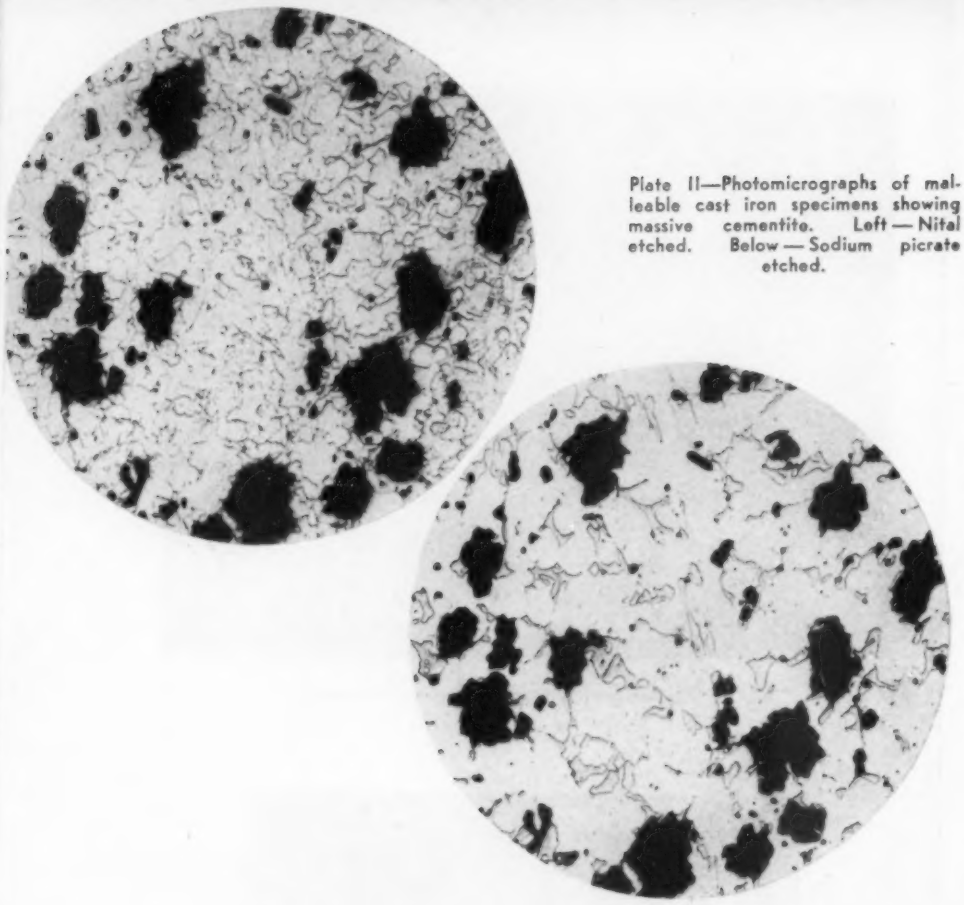


Plate II—Photomicrographs of malleable cast iron specimens showing massive cementite. Left — Nital etched. Below — Sodium picrate etched.

pearlite or cementite. From these indications firing is adjusted on the next heat. By this method faulty firing practice is corrected before the effect is serious enough to affect the castings.

Very small amounts of pearlite or cementite, although indicating faulty annealing, are not serious enough to affect physical properties or machining to a noticeable extent.

Plates I to IV show some of the structures that may be found in faulty annealing practice. These faults are shown in the order of the annealing cycle.

Plate I shows what will be recognized as normally annealed malleable, showing only ferrite and temper carbon, although it will be seen further on how, exceptionally, faulty malleable may show this same microstructure.

Cementite

Plate II shows a lack in the first stage of anneal, and indicates either too low a temperature in what is known as the soaking period, or too short a time at the temperatures attained. This is always shown by the presence of massive carbides or cementite.

The photomicrographs in Plate II show specimens etched by two methods. The photomicrograph on the left is etched with the most common reagent, nital, or 10 per cent nitric acid in alcohol, which does not differentiate between massive cementite and ferrite. Only the peculiar shape of grain boundaries will disclose the presence of carbides to the experienced metallographer. Massive cementite grains have peculiar curved boundaries, while ferrite boundaries usually are straight lines.

The sodium picrate etch, however, will tint the massive carbides gray and leave the ferrite white, as shown on the right-hand photomicrograph taken on the same spot as the left-hand one. This massive cementite cannot be removed in the second stage of anneal.

Pearlite

Plate III shows three examples of a lack in the second stage of anneal. This fault usually is expressed as cooling too rapidly through the second stage temperatures from 1400° F. to 1300° F., approximately. This fault is evidenced by the presence of pearlite.

These three photomicrographs show three different degrees of this fault. The first is just enough to give warning, but probably will not be even noticeable in physical properties or fracture. The second is appreciable and, although noticeable, probably would not be serious. The third, the well known bulls-eye structure, would cause a white or pepper-and-salt fracture and a serious change in physical properties, evidenced by increased hardness and tensile strength with low bend and elongation.

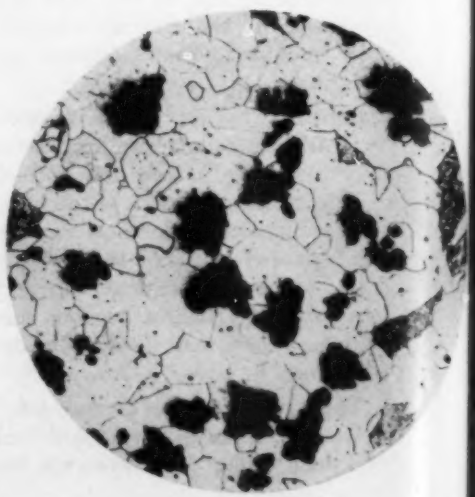
Plate IV shows a combination of lack in both first and second stage anneal, as evidenced by the presence of both massive carbides and pearlite, etched with nital and with sodium picrate to show how the latter distinguishes the carbide from the ferrite by darkening cementite and leaving the ferrite white.

Someone was in a big hurry to get this one annealed. They wanted it bad, and that is the way they got it—bad!

Ferrite and Temper Carbon

Returning to the fully annealed photomicrograph (Plate I) showing only ferrite and temper carbon. Once in a while (we have seen two cases in the last four years) a casting is submitted that is of normal hardness but will break short under impact, and with a completely white fracture.

When examined under the microscope, this casting shows complete anneal, only ferrite and temper carbon such as this sample (Plate I). This defect is caused by cooling too slowly after the last stage anneal, or in what is known as the subcritical range (below 1300° F.). This causes intergranular fragility, causing the metal to break through the



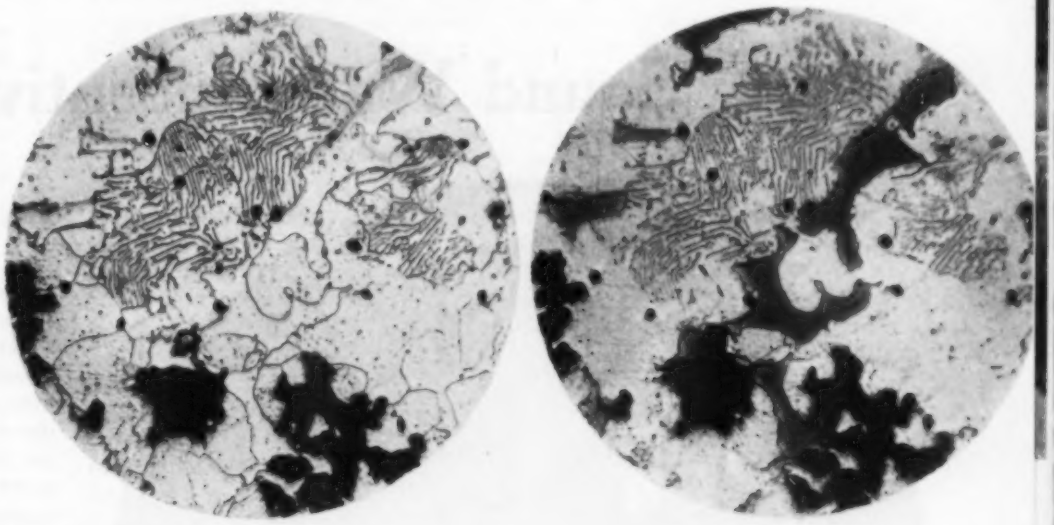


Plate IV — Massive carbides and pearlite are quite apparent in these photomicrographs of malleable cast iron specimens. Left — Nital etched. Right—Sodium picrate etched.

grains instead of along the boundaries as is normal.

The normal break along the boundaries meets numerous temper carbon nodules, which gives the normal black or mouse-gray fracture. The break through the grains meets only by chance a temper carbon nodule and causes the white fracture. This defect usually is caused by allowing a very large annealing oven to cool down from the last stage without removing doors or providing some means of final rapid cooling.

Reheating to just under the critical range (about 1200° F.) and quenching in water will restore metal of this kind to normal properties.

Usually, if continuous microscopical control is exercised and no drastic changes in annealing practice are made from one annealing heat to another, the defects discussed will appear only in negligible quantities and can be remedied long before they become serious.

Summary

To sum up briefly, adequate malleable control may be attained by judicious sampling for analyses, proper mixing and blending of pig iron and scrap to average out variables, and by mixture control, melting control and annealing control.

One of the most difficult and probably impossible feats in manufacturing, as well as elsewhere, is to complete a series of operations twice in exactly the same manner. But how often do we hear in the plant—"But everything was exactly the same as it was yesterday." Do not we realize that if everything were exactly the same results would be likewise?

Control is simply the application of rules, habits, processes and apparatus to ensure, as closely as possible, duplication of results. Even with control, exact duplication is seldom and only accidentally accomplished, wherefore allowable variations in analyses and physical properties as well as in other specifications.

By controlling just a few of the greater variables, a marked difference will be noted in the regularity of results.

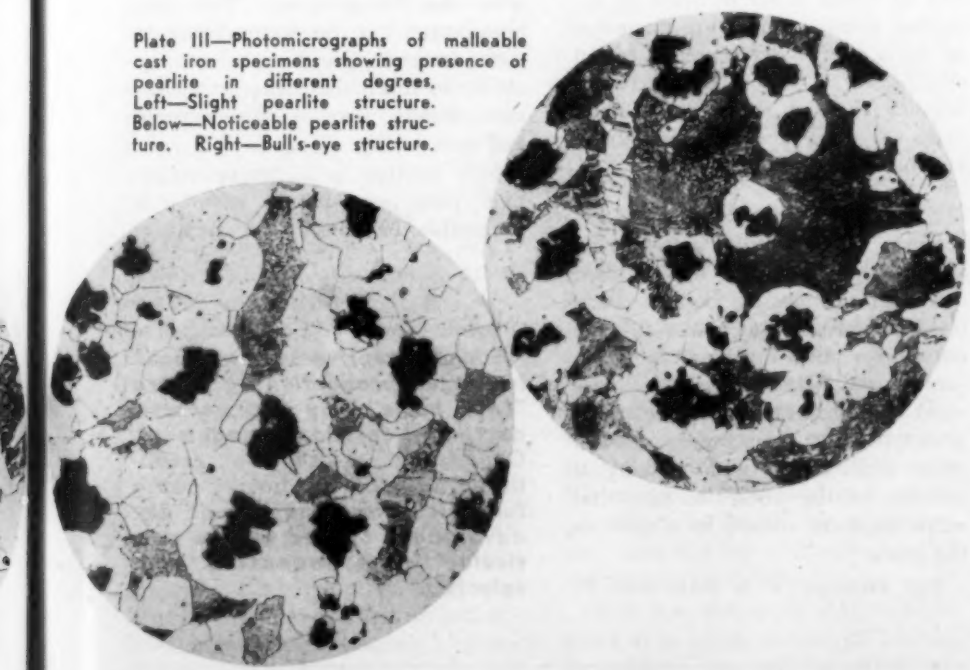


Plate III—Photomicrographs of malleable cast iron specimens showing presence of pearlite in different degrees. Left—Slight pearlite structure. Below—Noticeable pearlite structure. Right—Bull's-eye structure.

Sound Wage Incentives

By Harry Reitinger,
The Emerson Engineers, New York

Wage incentive plans should be explained clearly and fully to shop men.

WHEN a wage incentive plan seems to be the answer to a problem of wage inequalities—and in almost every plant it *is* the answer—do not think that you can simply decide to have an incentive plan, and expect both management and workers to throw in together. All evidence must be available. It must be in black and white, clear enough for both to understand, and foolproof enough so that the money involved can always be properly accounted for.

We all know that, basically speaking, an incentive plan gives extra pay for extra production—and if the incentive plan is functioning correctly it should and will encourage that extra production.

The question then arises: What incentive plan? There are several, and as many different ways of installing them as there are engineers to do it. All systems are based on establishing a level, or normal amount of work done, and paying extra for work accomplished above and beyond this norm.

Gain-sharing System

First, there is the gain-sharing type of system. Under such a plan, a worker receives his compensation for extra production above average output for time involved, but at a rate of pay which allows management to share in the gain, under the principle that management had a great deal to do with making it possible for the worker to *earn* that extra, so there should be a split on the extra.

For instance, if a man does 10 hours work in 8 hours, he is paid his entire rate for the eight hours, plus about 75 per cent of his regular hourly rate for the extra two hours. Management feels that it deserves the remaining 25 per cent for making it possible for the worker to speed up. For this reason, most unions do not like gain-sharing systems, and they tend to breed much dissatisfaction.

The worker feels, and justifiably so, I believe, that if he has produced more pieces in a shorter length of time, he is entitled to full pay for so doing, particularly since, as is obvious, the unit cost of each piece produced is lowered by a faster rate of production.

Another system is called the "step bonus," or the payment of a lump sum to the worker after a certain production level is reached. Yes, the bonus is an incentive,—to reach the level at which the bonus is paid—but not an incentive to increase production beyond that level

Why should the worker exert himself? He gets no more money *after* the bonus level. This step bonus plan can be discouraging to those workers who do not have the ability to reach the bonus level, and who finally become disheartened and quit trying.

Still another is a "group incentive" plan, used mostly when it is impossible, because of the nature of

●

• Sound incentive systems mean increased production . . . more "take home" pay for workers, decreased cost for management. Confidence must be established by accurate basing and a full, clear explanation of the advantages offered by the particular wage incentive plan selected.

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Committee on Time Study and Job Evaluation.

the work involved, to measure the output of a single employee. The production of a group of employees is measured, a norm is set up and over-production is paid for on the output of the entire group. It is then divided equally among the individuals in proportion to their weekly earnings.

This system depends almost entirely upon the type of people making up that group. If the workers get along together, if there is no animosity within the group to start with, a group incentive plan can work out successfully. A group incentive plan encourages the workers to be more closely united. It teaches them to work together, to give help and advice where needed and, in some measure, reduces favoritism and the handing out of "gravy" jobs.

Here individual jealousies, a factor to be contended with and minimized, are considerably reduced. Of course, a group incentive should be applied only where it is impossible to measure the work of individuals.

Some systems go a step further than group incentives and become plant-wide incentives. These are employed only when a plant wishes to install an incentive system immediately, and as a temporary measure until a smaller group or individual incentive system can be set in operation.

Standard Time Plan

I like the incentive plan which pays the individual a bonus, based on an unchanging unit, namely, "standard time." The "standard time" is the number of minutes or hours in which a given task should be completed.

Because this plan is so simple and yet so efficient, I believe that it is the incentive bonus plan which *does* have all the answers—the plan which is fair to management, fair to workers; it is the most direct way of measuring the output of an individual, and recompensing him according to his ability.

Management is offering workers a five-dollar bill for 50 cents, so to speak, but management has all the evidence in using a system of incentive based on standard time—evidence that it is not buttering up the workers for a good roasting. And if unions offer that plan to management, they too have the same valid arguments. Unions offer more production, and consequently more profit; they receive in exchange a higher rate of pay commensurate with individual ability.

It should be stressed that the justification for any incentive plan, the value of it, the fairness of it under any given set of circumstances, depends upon the way it is set up. It must be airtight and foolproof—and I believe that a bonus incentive paid on the basis of an accurate measure of standard time is just that.

Operation Timing

Timing of any operation has earned for itself a bad name. Many unions have complained, and with more than a small measure of justification, that some methods of timing or "speed-rating" are simply ways of eventually lopping off the pay check.

This is because the original standard time set for an operation was not set accurately and carefully. This is what happens. Those few of management who have been taking every possible means to cut salaries insist on re-timing an operation frequently.

In so doing they are careful to pick the fastest man and set the stop watch by his speed. As a result, the supposed "average" or normal production which the other workers are supposed to exceed in order to receive a bonus is really top speed rate, higher than only the best man can ever hope to reach. Therefore, no bonus is paid.

Unfortunately, some have gone even further. As soon as operators have stepped up their output to earn their bonus, even though the timing has been set at somewhere near the normal level, management has stepped in and, on some excuse or other, re-timed the operation, and reset the norm on the basis of stepped-up production.

This does not imply that management as a whole should be blamed for what a few of the more unscrupulous have done to abuse a good plan. However, if an efficient job is to be done in setting a standard time, it must be done on the basis of the conditions and methods of performing the operation.

This does not mean the operation as it is running now but the operation after it has been studied and perfected—after it becomes certain that with present knowledge that operation is being performed at a normal rate of efficiency.

Production Factors

Every one of us knows that work of any kind is accomplished with the least fatigue under these three conditions:

1. When an operator attains form in operation, when he can complete an operation with ease and facility, he can accomplish remarkable results with minimum fatigue.
2. If an operator is interested, he can endure temporary strain without harm.
3. It is always easier to accomplish a definite task than to accomplish the same work without predetermination.

For a given time, a definite result should be set. Furthermore, that time should be so set that an average good operator can beat it easily. Thus he can develop form and interest in the operation in a double manner—first, by beating the time, and second, by receiving a reward.

For the purpose of figuring the bonus, the efficiency of the operator is measured by dividing the standard time by the actual time; that is, taking the time set as efficient for the job and dividing it by the time in which the individual operator does it. For purposes of converting the figure into a percentage, it is multiplied by 100. The answer is the percentage of efficiency on a time basis.

Basis of Bonus Payment

Next comes the actual bonus itself. We have set the standard time of the operation and have found the efficiency percentage of the operator. Just how much money does the worker get after stepping up his work?

First, it must be remembered that since the basic unit is the hour, and all measurements are made on a time basis, changes in wage or wage rates do not affect the efficiency calculations—nor does the compari-

son of one period with any other period affect it.

Furthermore, the comparison between a machine molder and a pattern maker is fair because they are measured on the same universal basis, standard time.

It is obvious that when the actual time and the standard time are the same, performance is 100 per cent. Our organization has used and endorsed the system that bonus payments start at 80 per cent efficiency; first, because we believe the 80 per cent line offers an inducement to the worker to reach standard time and exceed it; and second, because such a margin takes care of fatigue, error and other allowances. Stated bluntly, we are none of us perfect, and it is only fair that the figures show it.

For each one per cent increase in efficiency the worker receives one per cent of his pay period straight time pay as a bonus. Thus at 100 per cent average efficiency, he receives 20 per cent of his pay period straight time as a bonus, and at 120 per cent efficiency he receives 40 per cent of that pay as a bonus.

Job Standards

It can be seen by this that no matter what the fluctuation of the base wage scale, this bonus rides right along with it. And this works out so that each worker is paid for all the time he saves.

Furthermore, since the standards set are basically correct, since they have been handled with as much care as is humanly possible, there are no easy jobs and there are no hard jobs. Each job's standard is fixed according to the job itself, each standard is individual and is not influenced by another job.

This eliminates any human tendency of an operator to push hard on the easy job so as to get more money, and to lose interest in the hard job. Since his bonus is based on his pay-period efficiency, he will plug hard to maintain a high pay-period efficiency.

The same standards apply to a beginner as to a skilled worker. As a beginner approaches and passes 80 per cent efficiency, he receives his bonus based upon his lower hourly rate, just as a skilled worker would receive it on his higher rate.

Such a bonus focuses the attention of both worker and the management on time, output, and quantity instead of rates. The hourly and daily wage rates are established by bargaining and job evaluation, and when set usually remain stationary for some time.

Re-timing Unnecessary

If the original setting of the standard time has been handled with care, there is no need for, no reason for the frequent re-timing that workers so much resent. There is no opportunity to readjust the efficiency level and make it higher if the workers themselves have, because of the incentive, raised their own efficiency. Efficiency is set on the job itself, and as far as possible on human capabilities, not on historical records of this job, nor on pace-setting performances.

These standard times should be studied and set by an unbiased agency—an engineer or group of engineers employed by the firm only for this job. If this is done, neither management nor labor can complain that one or the other set it up to suit one faction and thwart the other.

How is the bonus paid? It is figured on the basis of the worker's average efficiency over a pay period, his average straight time earnings during that period. Obviously, the average is taken to save an immense amount of clerical work, and there is, therefore, only one calculation to be made for each worker at the end of each pay period.

For psychological reasons, the bonus should be figured and paid separately from the guaranteed pay. Let the worker see in black and white right on his pay record just how much he has earned over and above his salary.

It is inevitable that he will talk it over with some of his friends in the plant—and inevitable that he will learn how his ability compares with the others. If he is satisfied with the original timing of his job, satisfied with his job, then he knows it is absolutely up to him as to how much "take home" pay he gets.

Worker Efficiency

Of course, the job order shows the standard time for the job the worker is doing at any given moment. He can figure his own efficiency at any time, check and compare it with the record in his pay envelope.

Because a worker's efficiency goes up, this does not and should not lower his basic hourly rate of pay. He is guaranteed this hourly rate as long as he is in good standing and has been asked to report for work. The only relation the bonus has to the hourly rate is in that the percentage of efficiency is paid for in direct relation to this established rate for his job.

We have been discussing the advantage that an incentive plan, properly handled, has for workers. But, what about management? No doubt about it, management is just as satisfied as the worker who sees his pay envelope swell by dint of his own efforts.

A good bonus system reduces unit labor cost and reduces the *total* unit cost by distributing overhead over a greater output. Furthermore, it provides a means of direct comparison of the efficiency of the workers, departments as a whole, divisions, and, yes, even a direct comparison of entire plants.

Naturally, such a comparison is invaluable to management in getting an accurate picture of just what is happening, even to the most remote detail of any job.

Basis of Wage Increase

Another point in direct relation to the lowered unit cost is the fact that lower unit cost is the only basis on which the War Labor Board grants an increase in wages. Therefore, with an incentive plan in good operating order in the plant, wages can be increased, but in terms that are commensurate with the worker's ability. Because the worker himself is responsible for lowering the unit costs, i.e., by increasing his own production, therefore, the worker himself is responsible for his own pay increases.

I cannot say too strongly that close cooperation between all concerned is absolutely necessary to make a success of any wage incentive plan. If both management and workers know what the other fellow is up to—if all parts of the affair are down in black and white in simple language for everyone to understand, we will find that a sound wage incentive plan will be acceptable.

From the first moment a management decides to install such a system, not only must the unions involved be consulted, but the individual worker must be informed. A

printed outline, clearly organized, and understandably written, is always helpful.

Before a man's job is investigated and analyzed in order to determine the standard time for the operation, the worker himself should be consulted for suggestions. Perhaps there is a difficulty about the operation which he would like straightened out. Perhaps he has an idea for improvement of the operation, but has had neither the time nor quite enough knowledge to go about making that improvement.

A wise, thorough engineer can help him. It must be explained to the worker that the reason his job is being timed is to ascertain a time within which the job can be completed with maximum efficiency—that it is not being done in order to cut his pay, but in order to help him earn more money.

If this is done, nine out of ten workers will throw in with the management and end up by being as eager and interested in the whole project as the originators.

Operating Delays

Once an incentive system is installed, delays to operators and machines must be avoided. If there is a bonus awaiting "Joe" while he is working, he is not going to be very happy about sitting around waiting for work.

It is always wise to check the office or desk from which the planning, scheduling and dispatching of work comes. See that they keep ahead of the worker, keep him busy with just as much work as the man wants and can take.

Needless to say, the machine setup must be done correctly, and so as not to interfere with the worker. The work in process should be well-timed so that if one man is dependent on the output of another to get his work, he need not be delayed. Arrange it so that the man who would ordinarily be waiting for work because he is faster, is able to get his material from a second person when he needs it.

The question of preventive machine maintenance is always present. A breakdown in a machine is quite a sour proposition to the worker if it means a breakdown in his bonus as well.

When I outlined the setting of the standard time for an operation, I mentioned that there should be little need for re-timing a process if the original work has been done with care and skill. I did not amplify it at that point, because I wanted to bring it up again here, under this general series of cautions.

Occasions for Re-timing

As previously stated, frequent re-timings are unnecessary. There are occasions when, say, improvements in the machine or methods or both have been installed and the operation can be accomplished in a much faster time than before—and I repeat, because and only because improvements have been made, not because the man has attained a higher degree of efficiency, is re-timing in order.

If the improvements have been installed through the initiative of the management, then, having gone through the proper channels, the job should be re-timed. However, this should not result in a loss of pay for the worker; if it does, it is evident that either the new time or the old is inaccurate—and it will mean a most disgruntled employee.

If the improvement has been installed through the interest of the employee—if he has suggested or designed the improvement, then he should have the credit for it, if it is even in the least traceable to him.

Lump Sum Payments

Perhaps the management may find it the wisest plan to pay the employee a lump sum for the improvement, equal to what his earnings would be if he were paid on the basis of his new output and his old standard time over a period of one year—in other words, a year including what he would normally receive on an average, plus the bonus, payable at the same rate, on the difference between the old and the potential new output.

Then the operation can be retimed without any hard feelings, and the actual normal rate of the man and machine will be in keeping with normal rates on other machines that have not had a major improvement.

Some companies may prefer to let the man increase his own bonus by allowing him to work on his old standard time and step his production above standard as much as the improvement will let him, taking his proportionately increased bonus. I rather like the former method; it prevents jealousies being continued over a long period of time.

Still another problem almost always offers itself whenever and wherever an incentive system is installed. And it is—what shall we do with the day workers—workers whose jobs cannot be figured on the basis of operations—workers who are just as vital to the production of the plant, and yet whose output cannot be easily measured?

Day Workers

Consider the case of a cupola tender, for instance. How can he be placed on an incentive basis; one which is commensurate with his ability? How can he be paid a bonus for extra production?

That question is not as much of a poser as it may seem, even though it is getting rather close to another subject, that of job evaluation. It can be answered with little detail that in such cases, if a man's job is evaluated carefully, not of course on a standard time, but estimated, evaluated, he will be getting an hourly rate commensurate with his ability and skill.

However, that does not completely settle the day worker's lot. If the rest of the plant are on incentive pay and have stepped up production, the day worker also must work harder, step up his own production to keep pace with the incentive workers.

In a great many cases, and with much to be said for their point, unions have fought for and won extra-production pay for day workers who are employed along with workers on incentive pay. In other words, suppose production had, as an over-all picture, increased 35 per cent among incentive workers. The day workers, who must also have stepped up production, should also receive extra-production pay amounting to the same percentage.

Summary

Establishing a good, sound incentive system in a plant means that production is increased, "take home" pay is increased, profit is increased, and, of course, costs are decreased. Workers are paid on the basis of the amount of work they can do accurately in a set period of time.

In other words, the individual worker is paid commensurate with his ability. To take care of a re-

sulting discrepancy, day workers are brought up to correspond to the over-all percentage of increased production. I advocate incentive plans if they are sound and workable. I heartily endorse them and hope to see the day when they are installed in all plants where it is possible to do so. To my mind, it is a great forward step in industry to recognize by a pay check the differences, the variations in ability of all men.

Equipment Trends in

PRECISION CASTING

• *Precision casting, as a means of producing intricate castings to close dimensional tolerances and eliminating slow and costly machining operations, has proved itself in war production. Equipment and methods developments indicate extensive post-war applications of the precision casting process.*

By Capt. A. J. Dore,
Chicago Ordnance District,
Chicago

MOST foundrymen are quite familiar with the general procedure involved in precision casting. Several excellent articles on the subject have been published by Neiman[1] and others.

Table shows an outline of the principal steps involved. The first step is the manufacture of patterns, which differ from those used in normal foundry practice because a pattern is expended for each cast made. This means that an inexpensive method must be used for the production of the patterns.

It also follows that no matter how inexpensive these patterns become, they are almost sure to cost more than the amortized cost of the single pattern used in normal foundry practice. The justification for this expense and all the other new expenses is the reduction or total elimination of machining which follows from their use.

In general, the pattern material is either wax or plastic. Wax is more common, and comes directly from the dental and jewelry practices. The plastic pattern is a new addition to the pattern family, and was introduced by industry. In general, the use of wax permits a lower initial investment, since inexpensive wax injection machines are available, whereas with plastic patterns, a plastic injection molding machine must be used.

In addition, low cost injection dies for the production of wax patterns can be made by casting a low-melting alloy around a master pattern, as compared to the high cost of making a plastic injection die.

This cast die technique for wax pattern manufacture is a direct take-off from dental practice. The first step is shown in Fig. 1*A*. A master pattern (5) is carefully placed in modeling clay to its parting line in one half of the die set. As shown in Fig. 1*B*, fusible metal (6) is poured over the master pattern to form one mold half. After cooling, the modeling clay is removed and replaced similarly with the fusible metal.

The result is a die for wax pattern production which is suitable for small production. By adding the following additional step, higher temperature alloys and pressure can be used to obtain a more durable die. This step comes between *A* and *B* (Fig. 1), and consists in filling space (6) with a hard-setting plaster material. After the plaster material has hardened (½ hr.), the die is inverted, the modeling clay removed, and molten alloy metal substituted.

Pressure is applied to the molten alloy until solidification occurs. This completes the first half of the die. The plaster material is then thoroughly removed from the pattern and the half of the die which has just been completed; their surfaces are dusted with graphite and again molten alloy is poured in and placed under pressure until solidification is complete. The die is now completed.

This type of die, while not generally recommended for the production of highly accurate parts in large quantities, does stand up remarkably well when properly supported and used.

A die for the plastic patterns is generally produced by standard toolroom methods and gives a fairly long life. Each injection with the plastic injection machine results in one or more complete patterns. This is not necessarily the case with wax patterns, due to the large shrinkage which occurs in the wax. The solution to this problem consists of molding wax inserts for the thicker sections. These are inserted cold into the appropriate position in the pattern die to reduce the shrinkage in these troublesome thick sections.

It is always necessary that great

PRECISION CASTINGS

Patternmaking		Investing	
Wax	*Plastic*	*Coated*	*Uncoated*
Master pattern	Metal die	Mix investment	Mix investment
Metal die	Injection mold	Invest	Invest and tamp
Injection mold pattern (1 or more steps)		Tamp	Tamp
Assemble	Assemble	**Drying and Heating**	
Dip Coat		*Wax*	*Plastic*
Prepare dip coat		Air dry	Air dry
Dip		Melt pattern out	Burn pattern out
Sand		Heat to casting temperature	Heat to temperature
Mounting		**Casting**	
Wax cement pattern to base (metal or rubber)		*Gravity*	*Pressure* / *Centrifugal*
Asbestos liner		Melt	Melt / Melt
Wax cement container to base		Pour	Pour / Pour
Ceramic Mixing		**Cleaning**	
Mix investment solids		Press out invested cast	
Mix investment liquids		Cut-off	
		Sandblast	
		Clean	
		Finish machine	

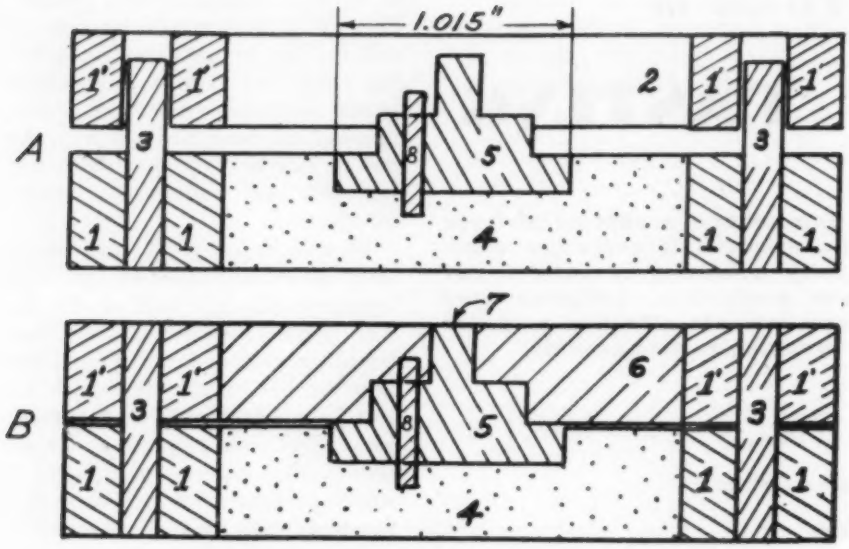


Fig. 1—Patterns used for wax pattern manufacture. Top (A)—Pattern placed in molding clay in one half of the die set. Bottom (B)—Fusible metal poured over the master pattern to form one mold half.

care be given to the placement of the feeders for the injection of the pattern material (this applies to plastic as well as to wax patterns) so as to achieve directional solidification beginning with the portions furthest from the feeder and ending with the solidification of the feeder. This reduces the tendency towards incomplete patterns which happens whenever solidification occurs first between the feeders and more remote portions of the pattern.

Figure 2 shows a production type wax injection machine. The square-shaped container in front of the operator holds the molten wax. The operator's right hand is on the hand-operated hydraulic pump which provides the die clamping pressure, and the left hand is on the die blocks. Close control of wax temperature and injection pressure is maintained.

The dies are carefully inspected for cleanliness before each operation. Any residual wax is removed by brushing with carbon tetrachloride. Figure 3 shows the operator lubricating the die prior to the injection molding operation to facilitate removal of the pattern. In front of the operator is a block of dry ice used to prevent the mold from becoming too hot.

In making plastic patterns, a standard plastic injection molding machine is in general use. The plastic powder is fed from a hopper into a heating chamber, where it is heated to a closely controlled temperature. From this chamber, the liquid plastic is automatically fed into the die with each operation. The cyclic time is controlled by the operator.

Several patterns are generally mounted on a sprue—either directly or through intermediate risers and runners such as shown in Fig. 4. Attainment of the maximum output per mold is even more necessary for investment casting than for normal foundry casting due to the high cost of the investment material. Patterns, sprue and feeders, both wax and plastic types, are cemented together by first using a heated knife or spatula to wet the mating surfaces and then holding them in contact until setting is completed.

Most manufacturers use a dip coat on the pattern and back it up with investment. This undoubtedly permits the use of a less expensive investment than would be the case without it. Coarser investment ma-

Fig. 2 (Below)—A production type wax injection machine.

Fig. 3 (Right)—Lubricating a die to ease pattern removal. Note block of dry ice for cooling die.

terials are also used, resulting in greater porosity which, in turn, cuts down the drying time for the investment.

This dip coat consists of silica flour suspended in a suitable binding liquid. The patterns are dipped into it by hand and then sanded to provide a coarse surface with which the investment can readily form a bond. They are then allowed to dry for 2 days.

After drying, the dip-coated patterns are generally mounted on a steel plate. This is accomplished by pouring hot wax on the plate to form a thin, tacky coating on which the pattern assembly is placed so as to rest on its sprue.

Some concerns have used a rubber base with a pre-formed hole, which fits snugly about the sprue instead of the metal plate. In this case, a small amount of hot wax is poured around the edge of the sprue to insure a perfect seal between the rubber and the sprue, since even a slight leakage of the investment after pouring would leave weakened areas within the investment.

A metal flask, which can withstand high temperatures, is then lined with a waterproof paper which extends about 3 in. above the top edge. This lined flask is then placed on the base (steel or rubber) plate and cemented thereto with hot wax to prevent leakage of the investment, as was the case with the junction of the rubber base and sprue.

Ceramic Mixing

The investment material in all cases consists of suitable refractories mixed with a liquid binder. The resulting investment must possess adequate strength at the pouring temperature and must not react chemically with the molten metal.

This is especially important with precision castings, since no allowance is made for finish machining to remove any surface defects, whether chemical or physical. Silicon-dioxide sand, in general foundry use, is also the common solid used in precision castings. Magnesium oxide is sometimes added.

The sieve sizes of the solid materials must be closely controlled. If they were all of one large size, the voids would be too great. If the percentage of fines is too high, cracking of the investment occurs due to the surface absorption of a large quantity of binder, the high shrinkage of which causes cracks.

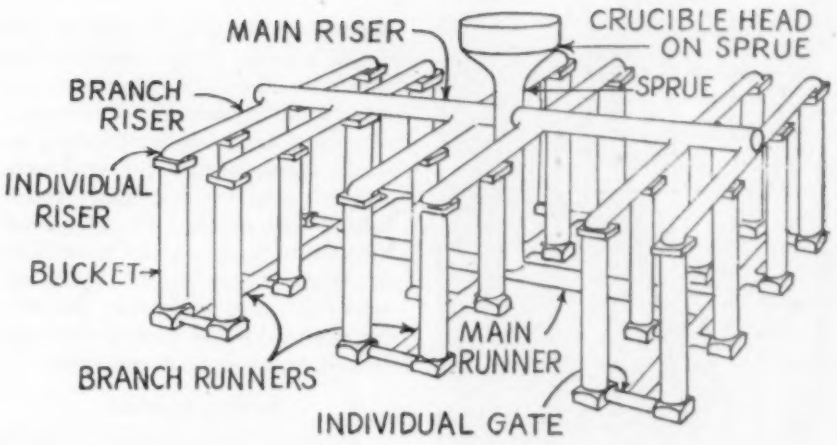


Fig. 4—Several patterns can be mounted on a sprue directly or through intermediate risers and runners.

Those manufacturers who do not use a dip coat require refractories which have a higher percentage of fines in order to achieve the same surface finish. However, since both the dip coat and the investment materials are very complex subjects and were thoroughly covered by Glaser,[2] their detailed discussion will be omitted. The actual mixing equipment required is very simple. Tumbling barrels and mullers are commonly used.

Investing the Pattern

The patterns mounted within the flask are now placed on a tamping or jogging table. The investment is slowly poured around them with a scoop while the jogging tends to eliminate air bubbles which may be entrapped in the investment as a result of either the mixing or this pouring operation.

Most of the manufacturers fill the flask plus about 3 in. of additional height; the additional height being achieved by means of the aforementioned waterproof paper liner which is around the inside of the flask. However, other manufacturers use longer flasks to start with. The jogging is continued for at least 45 min. until the solids have settled and have been closely packed around all portions of the pattern.

The flasks are allowed to rest quietly until setting is completed, whereupon the top 3 in., which extends beyond the flask, is cut off with a knife and discarded. This removes the extremely hard, dense outer surface and exposes a portion of a more permeable surface, which facilitates drying. Even with this assistance, a minimum of 8 hr. is required for drying. The base plates are now removed.

A steam table, which has openings about the size of the sprues, is used to remove the wax-type patterns. The flasks are placed on the steam table, with their sprue ends down and in line with the table openings, thus permitting the steam to melt out the wax. For all practical purposes, the steam licks the wax out, and avoids heating the entire body of wax at one time, thus eliminating the possibility of the wax pattern expanding and cracking the investment.

This differs from the procedure with plastic patterns which are burned out. With a plastic pattern, the entire mold must be heated so that it expands at the same rate as the pattern in order that investment cracks may be avoided. When the ignition temperature is reached, the plastic pattern burns. The plastic is thus a total loss.

Investment Expansion

However, the melted wax pattern is caught and can be used for sprues, runners, gates and risers. Only new wax is used for the pattern itself. The molds are then placed in an oven, still in an inverted position, that is, with the sprue end down, and very carefully brought up to pouring temperature.

The slow heating is necessary in the lower temperature range to prevent a violent evolution of the residual volatile constituents which would cause breakdowns. In the

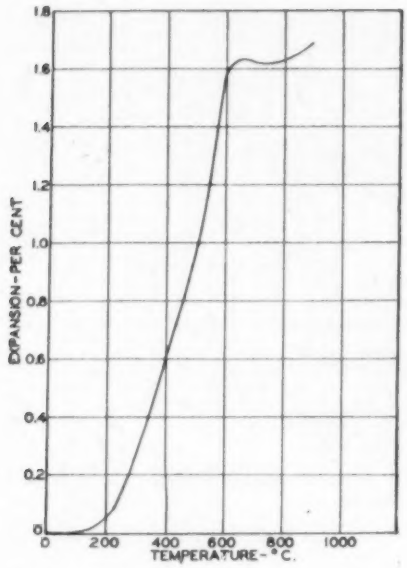


Fig. 5—An expansion curve for a silicate investment bonded with ethyl silicate.

higher temperature range, there is the problem brought up by the expansion properties of the investment.

A typical curve for a silicate investment bonded with ethyl silicate solution is shown in Fig. 5. It will be noted that the expansion is fairly constant, but high from about 392-1112° F. (200-600° C.). Between 1112 and 1472° F. (600 to 800° C.) there is an actual shrinkage of the investment. Naturally, the temperature rise through these regions must be carefully controlled if cracks are to be avoided.

Any wax not removed by the steam burns out during the early part of this heating cycle. Obviously, the final or pouring temperature depends upon the composition of the metal which is to be poured.

Some of the factors which are partially controlled by the temperature of the mold at the pouring time are allowances for the contraction of the metal from its solidification temperature to room temperature, grain size due to the amount of chill permitted, etc.

In dental and jewelry practices, it is customary to melt the casting metal by means of a gas torch. Naturally, with industrial alloys which are easily contaminated, this method has been superseded. Melting is generally done in either an arc furnace or an induction furnace.

The time per melt varies greatly with the different plants. Some manufacturers using induction melting strive to keep their melting time down to about 1 min. Such a short time undoubtedly contributes to easy control of chemistry. The supercharger plant using arc furnaces requires about 20 min. for each melt.

The metal is generally superheated 300 to 500° F. The exact amount depends on the complexity of the casting, its size, the grain size required, etc. In general, the lowest practical value is used and controlled by an optical pyrometer.

Pouring Methods

Three methods of pouring are in general use. The standard gravity head pouring, with which foundrymen are familiar; pressure casting, in which air pressure is applied to add an artificial gravity head; and finally, the centrifugal method, which is taken directly from the dental and jewelry practices.

Figure 6 shows the combination of an electric arc furnace in conjunction with pressure casting. The mold is mounted on top of the furnace with the sprue end down and lined up with the pouring mouth of the furnace. Note that the furnace is mounted on trunnions so that it can be rotated, and that the electrodes enter the furnace through these trunnions. An air-pressure connection is supplied at the bottom of the furnace.

In operation, the metal is first melted and properly superheated. The mold with furnace is then rotated about the trunnions, thus permitting molten metal to fill the mold by gravity. Air pressure is then applied through the furnace, and thus adds an artificial gravity head to the metal in the mold to achieve a dense, well-defined casting. This is the type of setup used by the supercharger plant in the production of supercharger buckets.

Centrifuging Machine

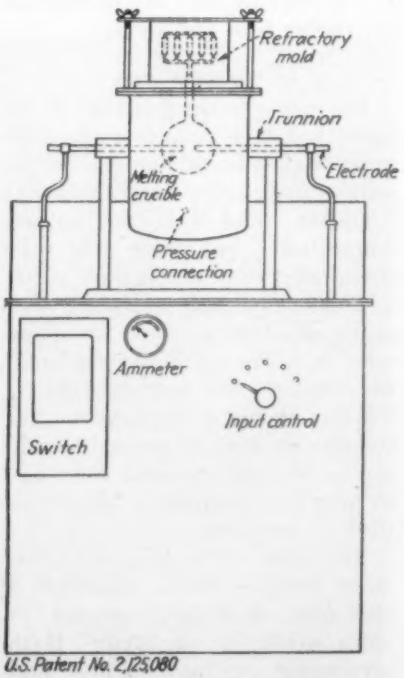
Figure 7 shows a modified dental centrifuge. The mold (7) is mounted at the extreme end of pivoted arm (11). The pouring crucible (8) is placed against the mold so that the molten metal, represented by dotted lines (13), will pour into the sprue opening due to centrifugal force when the unit is rotating. In addition, the arm (11) which holds the crucible and mold is pivotally mounted to the arm (1) which is the power driven rotating member.

Figure 7*B* shows the relative positions of the arms during the melting period just prior to centrifuging. Figure 7*C* shows the relative positions of the arms during centrifuging —the molten metal has left the crucible, entered the mold and has centrifugal force acting on the metal, as shown by arrow (5), thus giving the effect of a high pressure head.

Figure 8 shows another type of centrifuge which is somewhat akin to standard foundry centrifugal casting machines. An induction furnace is mounted on top. The centrifuge itself is completely inclosed for the protection of the operator in case of mold breakdown. When the metal is properly superheated, the furnace is tilted to pour through the center opening in the centrifuge.

Figure 9 shows the inside of the centrifuge. The center pouring cup is just below the center opening in the top of the centrifuge. Consequently, when the furnace is tilted the molten metal flows down into this pouring cup and then outward into molds which are mounted on each side. In operation, the centrifuge would be rotating rapidly prior to pouring. The design is arranged so that the pouring cup and the molds can be lifted from the preheating furnace and set in place with a pair of tongs.

Figure 10 shows the centrifuge with the pouring cup only in place.



U.S. Patent No. 2,125,080

Fig. 6—An electric arc furnace used in conjunction with pressure casting.

Note the adjustment on each side to take care of various lengths of molds.

In all cases, the metal is allowed to freeze before changing the mold conditions. In gravity casting, the mold is left untouched; in pressure casting, the pressure is maintained until solidification occurs; and in centrifugal casting, the centrifuge rotates until solidification is complete.

The invested casting is removed from the flask with a few blows from a hammer or by pressing it out on an arbor or kick press. Tapping with a hammer removes most of the investment, but a considerable part of the dip coat remains. The sprue, gates and risers are then cut off and discarded. The castings are then cleaned by sand blasting, tumbling or shot blasting. Necessary finishing, such as grinding off stems remaining from the cut-off operation, chasing threads, etc., is then performed.

Inspection has not been dealt with in this presentation, as it is a fit subject for a paper in itself—especially if x-ray inspection, as used in supercharger bucket production, is included. It is also unnecessary to give a description of the inspection equipment used in order to understand the manufacturing steps.

A more detailed examination of the equipment involved in the process may be helpful. The first step of the process, as previously discussed, is making the pattern. It might be mentioned at this time that the pattern itself is the greatest single source of dimensional variation. Figure 2 shows one of the more elaborate present day wax injection machines. Its greatest lack of control is in the temperature of the die blocks.

Figure 3 shows the dry ice which is kept near the machine, and is used to prevent the die from getting too hot when in continuous use. This is certainly a very crude arrangement, not subject to close control, and which will certainly be improved in the future. The hand-operated pump could also be readily replaced by an improved arrangement.

The same comment about lack of die temperature control applies to the plastic injection equipment. The die temperatures are not controlled and must contribute substantially to the pattern variations which are commonly encountered. For ordinary production, this undoubtedly has no significance, but for the production of precision casting patterns it will undoubtedly be good business

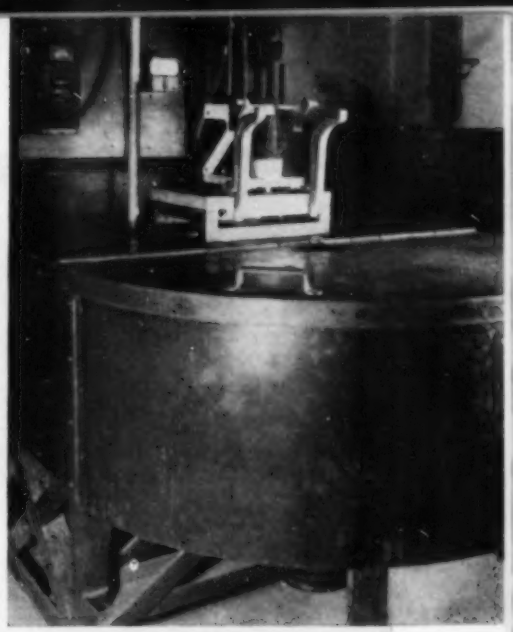


Fig. 8—Another type centrifuge with an induction furnace mounted on top.

to install temperature controls.

The development of a method for molding hollow plastic patterns is nearing completion. When completed, this method is expected to reduce the shrinkage and consequently the shrinkage variations as well as the tendency for the plastic pattern to crack the investment by expansion just prior to burn out.

Pattern Assembly

As mentioned previously, the wax or plastic patterns are assembled to the sprue, gates and risers by using a heated knife. For large production, this could certainly be made more automatic by at least positioning these components in fixtures, touching all the assembly spots in a given fixture at one time with a heated plate and then assembling mating fixtures, and thus substantially reduce the labor requirements.

The dip coat and the investment materials are presently handled without close controls. This is undoubtedly responsible for some of the rejections due to investment cracking which later occurs. For example; the sands, as supplied today, do not meet any rigid grain-size specifications. A no. 60 sand is merely a sand which has been in a ball mill for a specified time. Since the sand did not initially meet any particular specification, it is obvious that the resulting sand also will not meet any rigid specification.

This sore spot is currently handled by inspection of various sand lots, and selecting and using only those which come within the range which

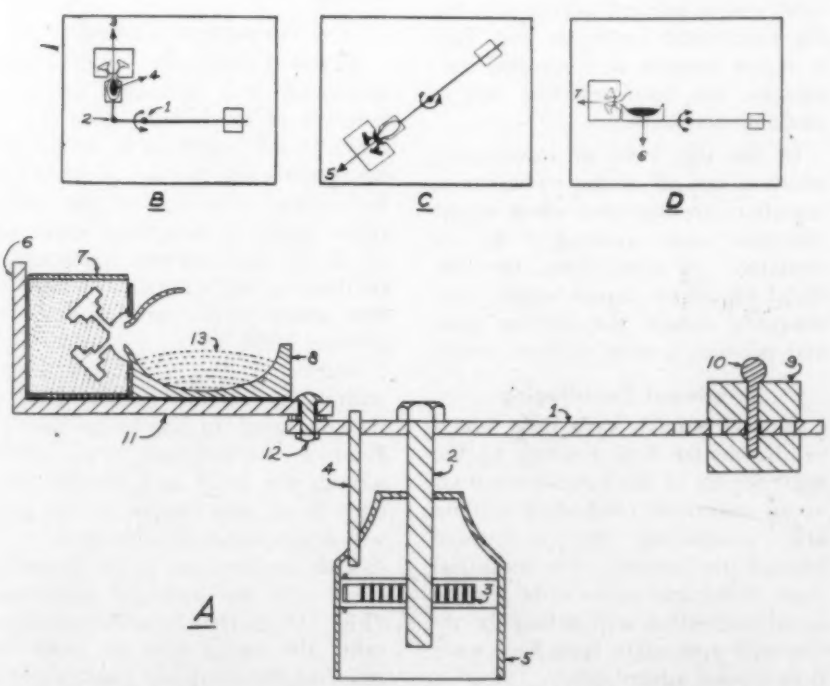


Fig. 7—Modified dental centrifuge. Mold (7) is mounted at end of pivoted arm (11). Pouring crucible (8) placed against mold (7) so that molten metal (13) will pour into sprue opening due to centrifugal force when unit is rotating. Arm (11) mounted to arm (1) which is power-driven rotating member. Fig. 7B—Relative positions of arms during melting period prior to centrifuging. Fig. 7C—Relative positions of the arms during centrifuging. Fig. 7D—Standard centrifuge.

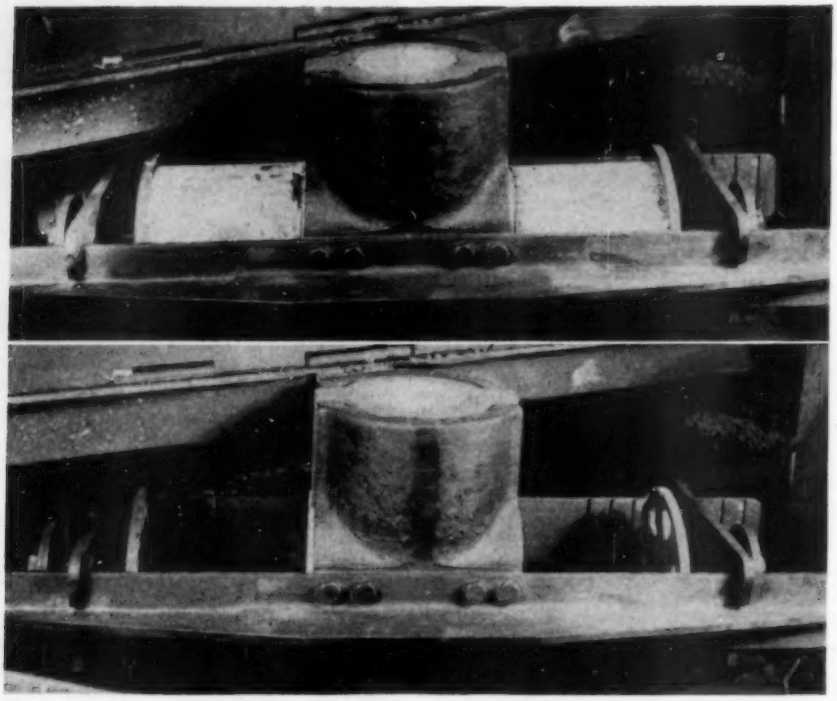


Fig. 9 (Top)—The inside of the centrifuge shown in Fig. 8. Molds on each side of pouring cup. Fig. 10 (Bottom)—Centrifuge with pouring cup in place.

is felt to be usable. Naturally, this is an unsatisfactory procedure. It would be easy to purchase sands of somewhat coarser grain sizes than that actually desired, and by the addition of finer sizes bring them to meet a fairly rigid specification.

The mixing of the investment, at least as far as the liquid additions are concerned, is left partially to the skill of the operator who, by experience, can state whether or not the right degree of consistency has been achieved. All of these operations will undoubtedly be accomplished in the near future by automatic weighing devices.

The dipping and sand spraying or hand sanding of the dip coat are hand operations whereby an operator works only on one pattern at a time. For large scale production, such as is occurring in some of the plants, automatic spray booths and the like could be worked out.

The molds are invested by hand filling, which at first sight appears to be a very backward way in this day and age. However, there are many problems involved in the handling of large quantities of the investment mixture, although none of them are believed to be insurmountable.

The function of the tamping of the investment, or jogging as it is commonly referred to in this investment field, is not completely understood. The author feels that it is not entirely a matter of compacting the investment uniformly, nor even a matter of finding a rate and amplitude which prevent segregation of the investment materials, but that a certain amount of controlled segregation has been achieved and is probably necessary.

In the top 3 in. of investment, which is cut off of the mold, many superfines are included which might otherwise cause cracking of the investment. A study from the colloidal chemistry aspect might considerably reduce the jogging time and produce a more uniform result.

Investment Centrifuging

Several patents have been issued in the dental field relating to the centrifuging of the investment itself as an improved method of settling and compacting the investment around the pattern. For industrial users, this might prove to be a more rapid method of compacting the investment and might even have some dehydrating advantages.

Pusher type furnaces are used in the larger plants for heating molds. For large scale production, a conveyor type oven would appear to be desirable, in view of the necessarily rigid time-temperature control requirements.

Another possible development in the heating line might be the use of die-electric heating, such as is currently used in the plastic industry. If it can be applied, it would permit much increased rates of heating without the accompanying risk of cracking the investment, as would occur in an unequally heated mold.

When it comes to the melting and casting end of the precision casting art, there seems to be great room for improvement, depending again upon the type of production. In fact, for research purposes, a totally new tool appears to be available, but unused so far. For example, it should be possible to induction melt and cast to close tolerances entirely within a vacuum, and thus achieve castings which are substantially free of occluded gases.

The author believes it to be entirely feasible to do this by a modified centrifugal casting technique or by modifying the pressure type setup to melt in vacuo and then allowing air to enter the furnace after the mold has been poured, thus obtaining a vacuum pressure casting. With vacuum pressure casting, the amount of air to be pumped out for any one cast could be kept to a very small amount.

Temperature Control

As stated previously, optical pyrometers are used to control the temperature of the metal. This leaves much to the judgment of the operator, prohibiting the use of unskilled help since each cast in this technique involves a separate heat of metal. It would appear worth while to develop an automatic temperature control which would initiate the pouring cycle.

Referring again to the centrifuge with a pivoted arm mounted on a rotating arm, as shown in Fig. 7. Prior to starting, the arm which mounts the mold and pouring crucible is at right angles to the arm which will cause them to rotate.

This arrangement is an improvement over the standard centrifuge (Fig. 7*D*) in that it facilitates delivering the metal into the mold by reducing the tendency for the metal to escape sidewise between the pouring crucible and the mold. However, as shown in Fig. 7*B*, the metal tends to move in the direction of arrow (4) which is still not in axial

alignment with the sprue opening and, therefore, causes unnecessary erosion of the sprue opening.

It would seem to be desirable to either move the pivot further out from the center of rotation while maintaining the mold and crucible in approximately their present position, and thus line the sprue opening up with the direction in which the metal will flow, or else to introduce a second pivot in the neighborhood of the junction of the mold and the crucible.

Where grain sizes must be fine, it would seem that automatic quenching means would be desirable. With the vitallium alloys this is unnecessary since allowing the molds to cool to about 400° F. before breaking the casting out results in the grain size which is specified and which, incidentally, is quite large. It would not be a difficult problem to provide an automatic quenching cycle for any one of the three types of casting which could be completely conveyorized.

Acknowledgment

The author wishes to acknowledge the courtesies extended by Austenal Laboratories, Inc., Chicago; Naval Research Laboratory, Washington; Whip-Mix Corp., Louisville; Allis-Chalmers Mfg. Co., Supercharger Plant, Milwaukee, and Illinois Precise Casting Co., Chicago.

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• A report of an investigation conducted under the direction of the A.F.A. Committee on Physical Properties of Foundry Sands at Elevated Temperatures, Subcommittee on Physical Properties of Steel Foundry Sands—reproducibility of hot compressive strength values when using two different type cylindrical specimen tubes.

SPLIT TYPE SPECIMEN TUBE

for Elevated Temperature Sand Testing

By D. C. Williams, A.F.A. Sand Research Fellow,
Cornell University, Ithaca, N. Y.

THE purpose of this report is to show some of the advantages of using a split specimen tube in forming a test specimen for the hot compressive strength from foundry sand mixtures. This work was authorized by the subcommittee of Subcommittee 6b7[1].

Twenty-three hundred hot compressive strength tests have been conducted at Cornell University, using (1) the usual one-piece specimen tube and (2) a split specimen tube (Fig. 1) for the molding of the 1⅛x2-in. test specimen. All of the work reported here has reference only to the molding of a cylindrical test specimen.

The reproducibility of test values is regarded from the viewpoint of tolerance limits for acceptable test values. Until more information is available regarding these limits, it is considered that any tolerance limits greater than plus or minus 5 per cent (hereafter referred to by the symbol α) from the arithmetic mean value (hereafter referred to by the symbol $\overline{X}$) would permit only a qualitative examination of the test results.

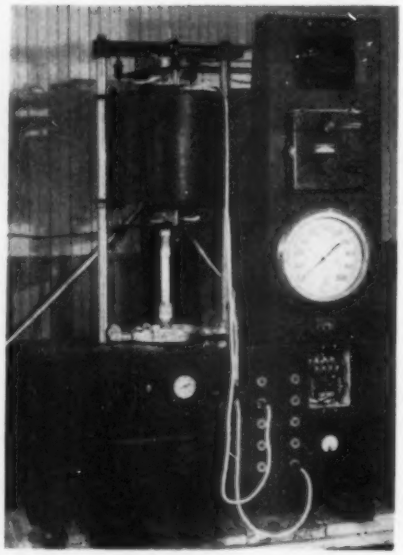


Fig. 2—Commercial equipment used in the elevated temperature sand tests.

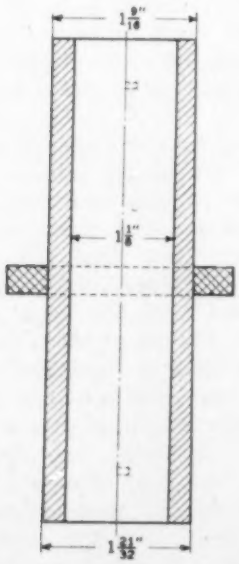


Fig. 1—Split specimen tube with sliding ring, tapered surface and hardened inside surface.

Up until the time when studies using the split specimen tube were begun, about 45 per cent of the test values obtained at Cornell University fell within the limits of $\overline{X} + \alpha$. However, most of these tests were made with the customary discs of 5/16-in. thickness. All tests reported here were made with discs of 1⅜-in. diameter and 1-in. thickness.

Testing Equipment

Figure 2 shows the commercial testing equipment used. Two departures from the usual testing procedure for this equipment were made and are as follows:

1. Change to different discs as mentioned previously.

2. A double bore fused quartz clear tube was used to protect the thermocouple wires. Better temperature control resulted from using this type of protecting shield. The tube appeared to devitrify without causing a noticeable change in temperature control of the furnace. Vollrath[2] also found a clear protecting shield superior to others, and also notes that devitrification occurred with little effect upon temperature control.

The thermocouple supporting block was transferred to the top cross bar for convenience of inspecting and changing the thermocouple.

Sand Mixtures. The eight sand mixtures used in this investigation

Table 1

SAND MIXTURES

Mixture No.	*Component*	*Per Cent*
1	Western Bentonite	4
	Sand	96
2	Western Bentonite	4
	Silica Flour	10
	Sand	86
3	Western Bentonite	4
	Cereal Flour	1
	Sand	95
4	Southern Bentonite	4
	Sand	96
5	Southern Bentonite	4
	Silica Flour	10
	Sand	86
6	Southern Bentonite	4
	Cereal Flour	1
	Sand	95
7	Fire Clay	4
	Sand	96
8	Fire Clay	4
	Cereal Flour	1
	Sand	95

Table 2

Mechanical Analysis

U. S. Bureau of Standards Sieve Number	*Retained, per cent*
40	0.51
50	10.15
70	40.95
100	35.40
140	10.90
200	1.92
270	Trace
Pan	Trace
Total	99.83

are listed in Table 1. Six batches from each mixture (48 batches in all) were made. The moisture content for all batches was held to 5.2 per cent ± 0.2 per cent. The washed and dried sand had the mechanical analysis shown in Table 2.

Testing Procedure. Testing was conducted at manual temperature

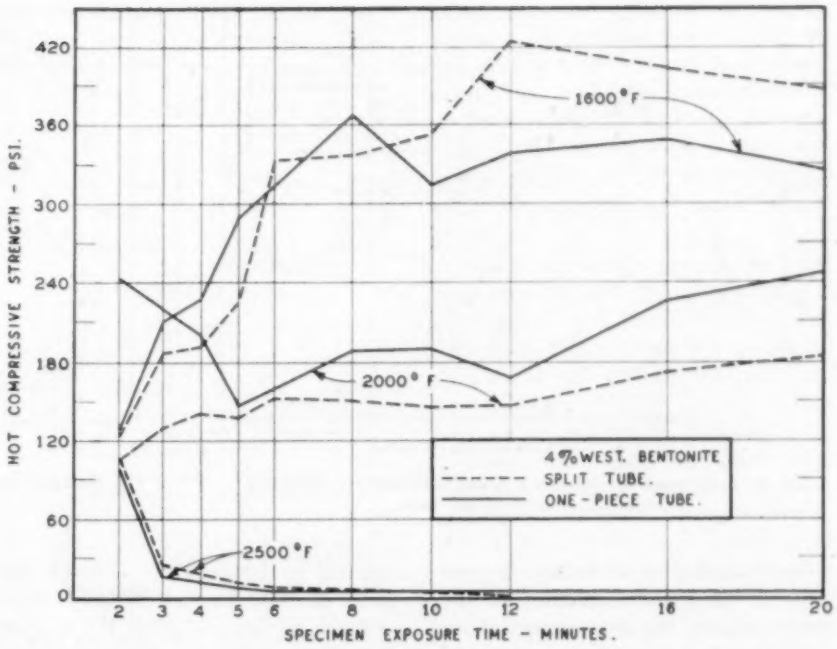


Fig. 3—Hot compressive strength values of green sand specimens made in split and 1-piece specimen tubes* from sand mixture containing 4 per cent western bentonite and 5 per cent moisture.

*Figures 4 to 10 show comparative hot strength values of specimens made in the two types of specimen tubes from various sand mixtures, all mixtures containing 5 per cent moisture.

Table 3

Number of Test Values Which Fall Within Limits of $\overline{X} \pm \alpha$
(where α = 5 per cent of $\overline{X}$ average)

With Split Specimen Tube

Material added to No. 60 N. J. Sand	*Western Bentonite*		*Western Bentonite, Silica Flour*		*Western Bentonite, Cereal*		*Southern Bentonite*		*Southern Bentonite, Silica Flour*		*Southern Bentonite, Cereal*		*Fire Clay*		*Fire Clay, Cereal*		*Percentage of No. of Tests within $\overline{X} \pm \alpha$ for Exposure Time*
Temperature Control Setting, ° F.	*1600*	*2000*	*1600*	*2000*	*1600*	*2000*	*1600*	*2000*	*1600*	*2000*	*1600*	*2000*	*1600*	*2000*	*1600*	*2000*	
Specimen Exposure Time, min.																	
2	1	5	4	3	3	4	1	2	3	1	2	4	2	1	3	1	50
3	5	2	4	4	5	4	1	2	2	5	2	1	2	1	1	1	52.5
4	3	2	4	5	3	3	2	2	3	....	2	1	2	2	1	1	45
5	2	3	4	4	5	3	2	4	5	3	4	....	2	....	2	3	57.5
6	5	2	4	5	2	3	2	2	5	....	2	3	....	2	3	4	48.5
8	4	4	1	1	2	5	2	....	1	2	1	2	2	4	1	5	46
10	5	5	3	5	5	5	3	1	5	3	....	....	2	1	2	3	60
12	4	4	5	3	4	5	4	3	4	3	2	1	2	2	....	5	63.5
16	5	5	3	5	3	3	4	4	4	2	3	4	2	3	2	5	71
20	3	5	4	4	3	5	5	4	3	1	4	2	3	2	1	5	67.5
Percentage of 50 tests within $\overline{X} \pm \alpha$	74	74	72	74	70	80	52	48	70	40	44	36	38	37	32	66	

With One-piece Specimen Tube

Specimen Exposure Time, min.																	
2	2	1	1	2	4	4	1	....	4	5	1	1			1	4	44
3	2	2	5	3	2	5	4	3	4	5	1	3			3	....	60
4	1	3	4	1	2	1	....	1	2	1	2	4			4	2	40
5	1	1	4	3	2	3	5	3	3	2	1	1			3	5	53
6	2	3	5	5	5	2	1	2	5	5	....	4			2	3	62
8	3	....	5	4	4	2	3	3	3	3	1	2			1	2	51
10	5	3	3	3	4	3	2	1	3	2	3	3			2	4	58.5
12	....	3	2	5	5	....	5	3	5	3	2	3			3	5	62
16	2	4	3	4	5	4	4	3	5	3	2	1			2	5	67
20	3	3	4	4	....	1	4	1	4	3	1	4			2	5	53
Percentage of 50 tests within $\overline{X} \pm \alpha$	44	46	72	68	66	50	60	40	76	64	28	52			46	70	

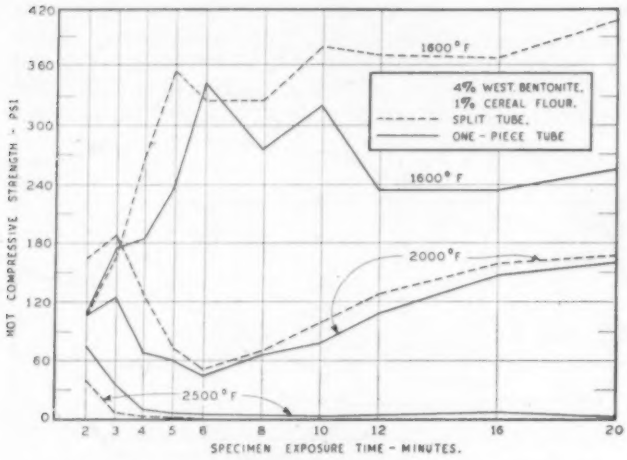


Fig. 4—Sand mixture containing 4 per cent western bentonite and 1 per cent cereal flour.

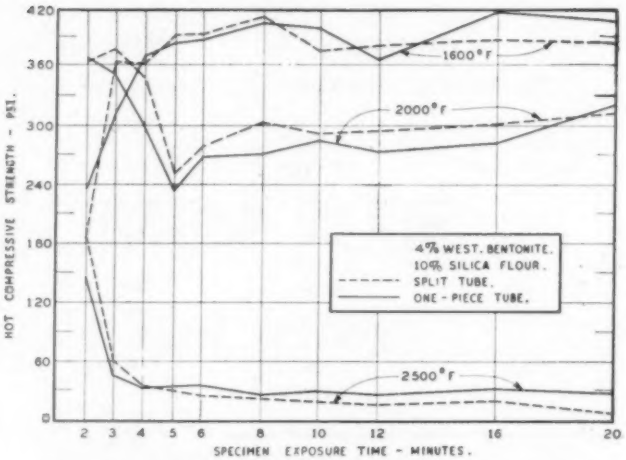


Fig. 5—Sand mixture containing 4 per cent western bentonite and 10 per cent silica flour.

control settings of 1600-2000°F. and 2500°F. After introduction of the test specimen the time required for the control point to be recovered was kept as close as possible to 2 min. and 15 sec.

The specimen exposure time includes the "recovery time" and up to the time when the upper disc and upper post made "contact," this being evidenced by a rise in gauge pressure after the tare load had been picked up. The time of exposure to heat after "contact" to maximum indicated strength averaged 30 sec., and this time is not included in the exposure time.

Five tests were made at each combination of exposure time and furnace temperature control setting. All five test values, regardless of spread of values, were used in computing the average values. In no case was a sixth test made unless a definite reason could be assigned to a discarded test value.

Comparison of Reproducibility with the Two Types of Specimen Tubes. Tolerance values were considered at temperature control settings of 1600°F. and 2000°F. At a control setting of 2500°F., a very large percentage of the test values fell below 10 psi.

Table 3 shows the results for the split and one-piece specimen tubes. Except for the right-hand column and the totals at the bottom of the table for each type of tube, the figures in each square indicate the number of tests out of five that fell within the limits of $\overline{X} \pm \alpha$.

The general average for all the tests with each type of tube indicated little difference found between the two types of tubes. However, this general average does not indicate that tests made with the split tube when western bentonite was added to the mixture were appreciably better than when made with the one-piece tube. The 4 per cent fireclay mixture gave trouble when using the one-piece tube. It was not possible to strip the specimen without damage; consequently, we have no comparison for this mixture.

During the ramming operation a "structure" is created in the test specimen. The test specimen keeps this "structure" when made in a split tube. When a one-piece tube is used the "structure" of the test specimen may be altered and the degree of alteration may depend upon the ease of stripping the specimen from the tube. The split specimen tube offers a greater chance of improving the reproducibility of test results.

Best Specimen Exposure Time. For purposes of reproducibility a specimen exposure time of 16 min. is indicated. The right-hand column for each type of tube, Fig. 3, shows the percentage of test values for each exposure time that fell within the limits of $\overline{X} \pm \alpha$. The split tube indicated 71 per cent of results within $\overline{X} \pm \alpha$ and the one-piece tube indicated 67 per cent of results within $\overline{X} \pm \alpha$.

A 4 min. exposure time indicated the least percentage of reproducible results for each type of tube. It may be noted here that for each tube the

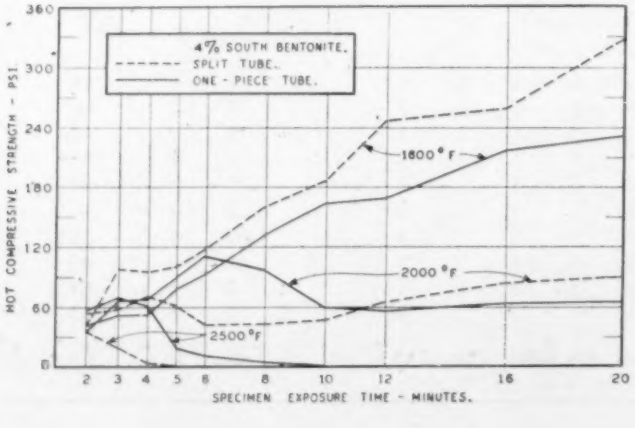
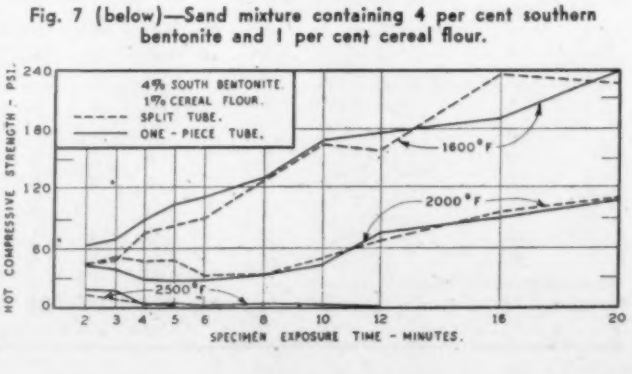


Fig. 6 (left)—Sand mixture containing 4 per cent southern bentonite.

Fig. 7 (below)—Sand mixture containing 4 per cent southern bentonite and 1 per cent cereal flour.



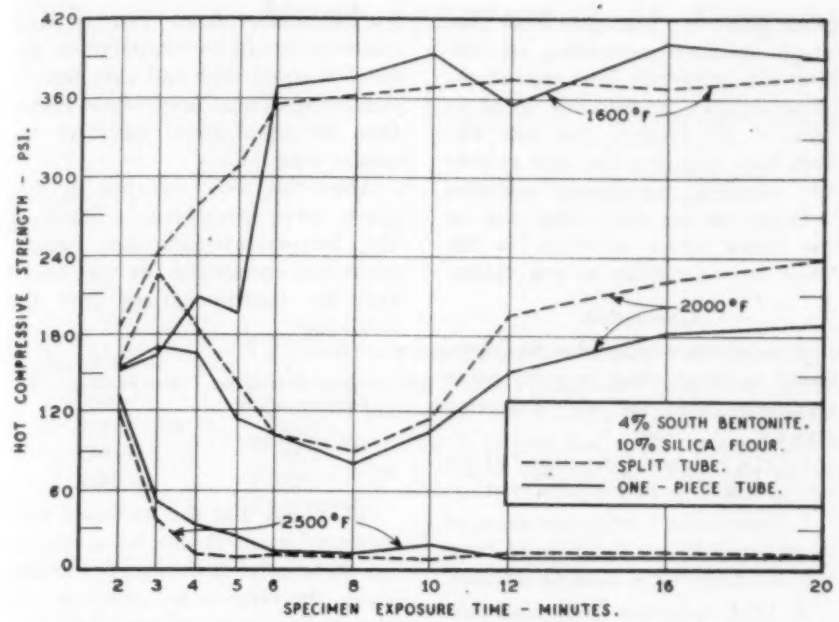


Fig. 8—Sand mixture containing 4 per cent southern bentonite and 10 per cent silica flour.

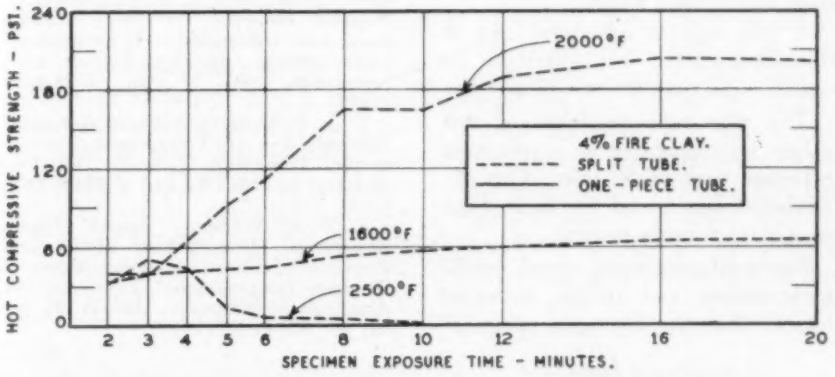


Fig. 9—Sand mixture containing 4 per cent fire clay. One-piece specimen tube could not be used with this mixture because of damage to specimen when stripping.

number of conditions of testing at which none of the tests fell within the limits of $\overline{X} \pm \alpha$ are about equal.

Comparing Sand Mixtures. It has been the usual custom to choose a certain exposure time at which all types of mixtures are compared. A certain degree of success has been found by some using this method. However, this type of comparison assumes that the test specimen is a one-piece specimen after being subjected to heat.

In the writer's Fourth Progress Report,[3] rinding and coring of the test specimen was discussed. This rinding and coring probably accounts for the test results shown in Figs. 3-10 at a specimen exposure time of 2 min. (used by several laboratories for control purposes).

It will be noticed that at an exposure time of 2 min. the hot compressive strength values at two or more of the temperature control settings were approximately the same. Because of rinding and coring of the test specimen there must have been two or three combinations of rind and core that gave similar test values. It follows that either the rind or the core will transmit the externally applied load until failure occurs.

The relative stiffnesses of the rind and core should be considered in connection with the rind and core formation. The respective core and rind areas will not be the same as the original specimen before it has been subjected to the furnace temperature. In addition, some test specimens increase in face area due to heating. It must be remembered that at present the hot compressive strength value recorded is only a *nominal value* and assumes a one-piece specimen which has not changed in face area.

Since heat penetration probably varies with exposure time and furnace temperature, it seems logical that various test specimen should be compared on the basis of equal rind and core formation.

It might be found, for example, when comparing the three mixtures containing western bentonite, that equal rind and core formation would take place at same temperature control setting as follows: 4 per cent western bentonite—exposure 6 min., 4 per cent western bentonite plus 1 per cent cereal flour—2 min., 4 per cent western bentonite plus 10 per cent silica flour—20 min.

For illustration purposes let us consider a mixture tested at three temperature control settings at 2 min. exposure. In addition, to simplify conditions, the core will be the

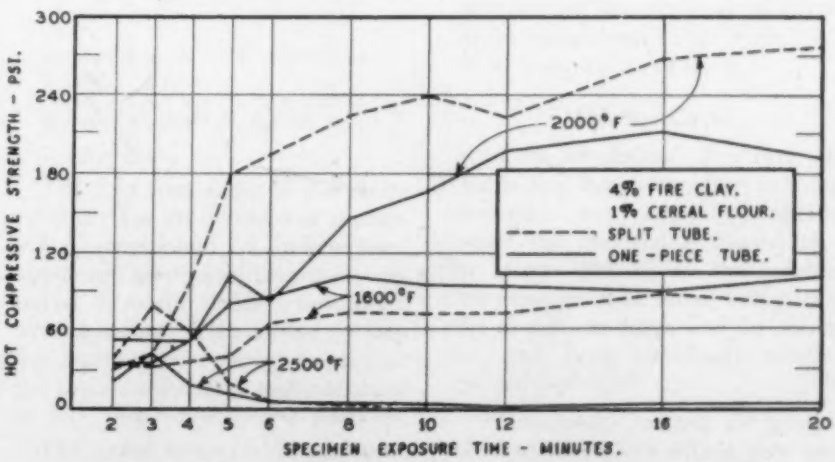


Fig. 10—Sand mixture containing 4 per cent fire clay and 1 per cent cereal flour.

only part of the test specimen which transmits the external load. In this case three combinations of rind and core yield the same value in pounds, but due to the smaller core area at the higher temperature the actual strength of a test specimen at temperature control setting of 2500° F. may be greater than the psi. at a temperature setting of 1600° F.

Accurate knowledge of furnace temperatures and rate of heat penetration into the test specimen will be necessary in order that two sand mixtures may be quantitatively compared. Since control laboratories in the foundry usually make all the comparative tests, these laboratories will have to be able to determine rates of heat transfer and have accurate knowledge of temperature distribution within their particular furnaces.

With the use of the split specimen tube, the reproducibility of certain tests averaged about 75 per cent within $\overline{X} \pm \alpha$. Since the only change in procedure was the type of tube used, which brought about a 15 per cent increase in reproducibility, it seems possible that studies on mixing and ramming might raise this reproducibility to perhaps 95 per cent of the test results within $\overline{X} \pm \alpha$.

All of the mixing was done in the same mixer with the same operating speed and rake settings. With this set-up, mixtures containing western bentonite gave the best reproducibility. It may be that this speed in rpm. of the mullers and rake settings does not give the best mixing for mixtures containing southern bentonite or fire clay. This may be one factor which accounts for the lower reproducibility of test values.

Conclusion

A split specimen tube has been found to be superior to a one-piece specimen tube for the following reasons:

1. The rammed "structure" of the test specimen is better preserved.

2. Specimens from a certain sand mixture could not be stripped from the one-piece tube without damage.

3. With specimen from sand mixtures containing western bentonite the reproducibility of test values within any one batch was consistently appreciably higher.

4. The type of split tube used in the investigation was found to be easier to use than the one-piece tube.

The best reproducibility of test values was indicated at a specimen exposure time of 16 min. This observation was found for both types of specimen tubes studied.

Since all specimens tested exhibited rinding and coring, it seems logical that the strength values of test specimens from various sand mixtures should be compared on the basis of equal rind and core formation or equal heat penetration rather than the usual equal specimen exposure time.

After the tests reported in this paper were completed, a study of the temperature-indicating equipment was conducted. It was found that the control settings gave the following:

Control Setting on Instrument, °F.	*Actual Control Temperature, °F. (Avg.)*
1600	1557
2000	1967
2500	2482

It follows that the indicated temperature is not always what appears on the control instrument. Furthermore, the error is not constant over the range of the control instrument.

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Heat Treatment of Magnesium Alloys

By D. Burks, R. F. Thomson and W. E. Jominy
Formerly with the
Metallurgical Department
Dodge Chicago Plant
Division of Chrysler Corp.

• ***Precautions must be observed in heat treating magnesium alloys to avoid "burning" and impairing physical properties of castings. Standard heat treatment for a 6 per cent aluminum, 3 per cent zinc magnesium alloy is presented. This paper should be of interest to producers of aircraft engine castings and to foundry metallurgists in general.***

THE common sand cast magnesium alloys in use in this country at the present time are primarily ternary alloys of aluminum and zinc with magnesium. The common impurities are manganese, silicon, copper and nickel. These alloys are frequently used in the heat treated condition as they are susceptible to precipitation hardening treatments. The solution treated state is used in applications requiring high ductility and the solution treated and aged condition is used, where improved yield strength is necessary at some sacrifice in ductility.

This paper presents data on the effect of pouring temperature, initial structure, heating rate prior to solution treating, solution temperature, solution time, cooling rate from the solution temperature, aging temperature and aging time on resultant static physical properties and microstructure of fine grained 6 per cent aluminum, 3 per cent zinc alloys. A brief study of dimensional changes during heat treatment is included.

Alloy Composition

The data reported here were obtained on the alloy whose nominal composition is as follows:

Aluminum	6.0%	
Zinc	3.0%	
Manganese	0.15%	minimum
Silicon	0.30%	maximum
Copper	0.05%	maximum
Nickel	0.01%	maximum
Other impurities	0.30%	maximum
Magnesium	remainder	

The results were obtained on standard 0.500-in. test bars cast four in a dry sand mold unless otherwise indicated.

The bars were cast with 20 per cent virgin metal and 80 per cent clean remelt scrap. The metal was superheated in 450-lb. crucibles for 15 min. above 1600° F. with a maximum temperature attained during superheating of 1675° F. The bars were poured at pouring temperatures between 1330° F. and 1460° F. The resulting grain size on all bars was between 0.003 in. and 0.005 in. average grain diameter.

Heat Treatment

The standard heat treatment applied to the test bars unless otherwise indicated was:

1. Charge in furnace below 500° F.
2. Heat to 650° F. and hold for 15 min.
3. Heat from 650° F. to 725° F. in 2 hr.
4. Hold at 725° F. for 12 hr.
5. Air cool.
6. Age at 350° F. for 16 hr.
7. Air cool.

The first four steps of the above cycle are for the purpose of dissolving a compound of magnesium, aluminum and zinc, commonly referred to as the "beta" constituent, in magnesium. The cooling in step five must be rapid enough to prevent the precipitation and agglomeration of the "beta" into coarse particles.

The aging temperature and time is chosen to allow precipitation of particles of optimum shape, size and distribution to give the desired physical properties.

For the sake of brevity, the following abbreviations will be used throughout this paper:

A.C. —As-cast material.
H.T. —Solution treated material.
H.T.A. —Solution treated and aged material.

The heat treat cycle previously described will produce physical property changes as shown in Table 1.

The yield strengths in Table 1 and all other such values given in this paper were determined by the extension under load method. An extension of 0.0089 in. in 2 in. was used which is approximately equivalent to the 0.2 per cent offset method.

Effect of Pouring Temperature on H.T.A. Properties. There is no significant effect of variable pouring temperature on the physical properties in the range from 1330° F. to 1460° F. as is shown in Table 2.

Solution Cycle

Effect of Initial Structure. In Table 3, is shown the effect of initial structure on physical properties when the material is heated in 2 hr. from 650° F. to the solution temperature. One set of bars was in the as-cast condition and the second set had been previously solution treated and aged.

These results indicate the properties are equivalent with a slow preheating cycle.

Table 1

EFFECT OF HEAT TREATMENT ON PHYSICAL PROPERTIES

	No. Bars	Yield Strength, psi.	Ultimate Strength, psi.	Per Cent Elongation, 2 in.	Brinell Hardness
A.C.	10	14,500	30,000	7.0	62
H.T.	9	14,800	41,000	15.0	60
H.T.A.	50	18,500	39,000	6.0	72

Table 2

EFFECT OF POURING TEMPERATURE ON H.T.A. PHYSICAL PROPERTIES

Pouring Temperature	Ultimate Strength, psi.	Yield Strength, psi.	Elongation, Per Cent 2 in.	Brinell* Hardness
1330° F.	38,860	18,360	5.9	72.5
1340° F.	39,060	18,380	6.0	74
1430° F.	38,220	18,600	5.9	72
1435° F.	39,200	18,440	6.2	73
1460° F.	39,000	18,500	6.2	73

*500 kg. load, 10 mm. ball.
All values are the results of the average of 50 test bars.

Table 3

EFFECT OF INITIAL STRUCTURE ON H.T.A. PHYSICAL PROPERTIES

	As-cast*	Previously H.T.A.*
Ultimate Strength, psi.	39,000	39,000
Yield Strength, psi.	18,500	18,000
Per Cent Elongation, 2 in.	6.5	6.0
Brinell Hardness	72	75

*Average 17 bars.

Table 4

EFFECT OF HEATING RATE ON H.T.A. PHYSICAL PROPERTIES OF AS-CAST MATERIAL

Time from Room Temp. to 750° F.	20 Min.	Normal Preheat
Ultimate Strength, psi.	38,000	39,000
Yield Strength, psi.	17,800	18,500
Per Cent Elongation, 2 in.	6.0	6.5
Brinell Hardness	74	72
No. Bars	8	17

Table 5

EFFECT OF SOLUTION TEMPERATURE ON H.T.A. PHYSICAL PROPERTIES

No. Bars	Solution Temperature	Ultimate Strength, psi.	Yield Strength, psi.	Per Cent Elongation, 2 in.	Brinell Hardness
(14)	700° F.	41,000	17,700	7.0	75
(12)	710° F.	40,000	18,300	7.0	73
(17)	720° F.	38,700	17,900	6.0	75
(13)	730° F.	40,300	17,800	7.8	74
(14)	740° F.	40,000	17,300	7.5	73
(12)	750° F.	40,000	17,300	8.0	71

Table 6

EFFECT OF VARYING SOLUTION TIME ON H.T.A. PHYSICAL PROPERTIES

Hours at 725° F.	No. Bars	Ultimate Strength, psi.	Yield Strength, psi.	Per Cent Elongation, 2 in.	Brinell Hardness
6	2	40,000	18,500	6.0	74
8	2	39,300	19,650	4.0	75
9	2	39,800	18,400	5.5	71.5
12	2	39,600	18,800	6.5	72.8

Effect of Heating Rate. In Table 4 is shown the effect of rate of preheat on the properties of as-cast material. One batch of bars was heated directly to 725° F. It required 20 min. to reach this temperature. Results are compared with those produced by the normal preheating cycle. It may be seen the properties are slightly superior in slowly preheated material.

Effect of Solution Temperature. In Table 5 are shown the results of varying solution temperatures on heat treated and aged properties. The bars used in this series had previously been solution treated and aged.

These data indicate temperatures as high as 750° F. produce satisfactory properties if no "burning" occurs during heat treatment. Temperatures as low as 700° F. also produce good properties. The reason for the selection of 725° F. as the standard solution temperature will be discussed later in this paper.

Effect of Solution Time. In Table 6 are shown some limited data on the effect of solution time on physical properties. It will be observed that times as short as 6 hours produce satisfactory physical properties in sand cast test bars.

Figure 1 is a photomicrograph showing microconstituents referred to in this paper.

Metallographic examination on pieces cut from test bars gave the results in Fig. 2, which shows the variation in "Beta" rating with time at solution temperature. The numerical system used is that proposed by George[1] and commonly used throughout the industry. No. 0 shows absence of "Beta" and 10 is the amount present in material as cast. Intermediate amounts are correspondingly numbered.

Comparison of Fig. 2 with Table 6 shows that acceptable physical properties are attained before solution of the "Beta" constituent is complete. The effect of these "Beta" nuclei on fatigue and impact properties is worthy of further investigation.

Effect of Cooling Rate. To determine the effect of cooling rate from the solution temperature on physical properties, seven different batches of test bars were cooled as shown in Table 7. The cooling rates

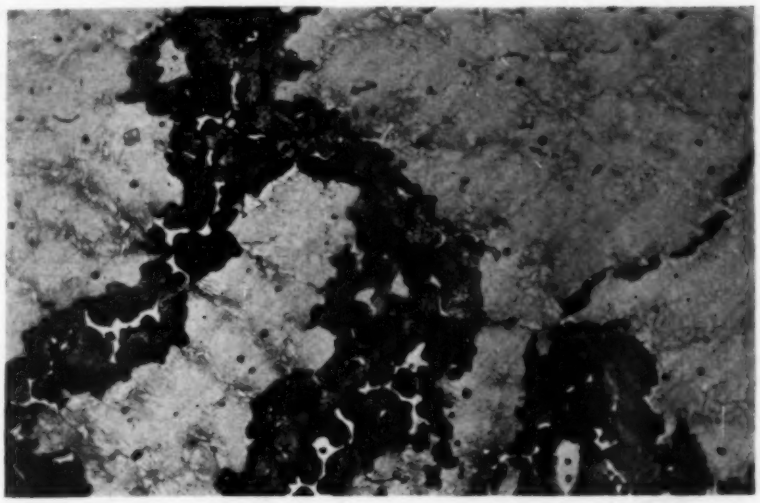


Fig. 1. Photomicrograph showing various microconstituents present in 6% Al, 3% Zn Magnesium Alloys. H.T.A. Condition.

were determined by axially drilling a test bar, imbedding a couple so the bead was at the center of the reduced section and cooling in a manner similar to that used for cooling the test bars.

The time interval to cool from 725° F. to 250° F. was selected as the criterion for cooling rate, since no visible precipitation of the lamellar constituent takes place at aging temperatures of 250° F.

It should be observed that the ultimate strength begins to decrease appreciably with cooling rates slower than 66 sec.

Effect of Initial Structure with a Rapid Heating Rate. Figs. 3 and 4 show the results obtained for a combination of rapid heating rate with varying initial structures. The bars were not preheated, but were heated to the solution temperature in 20 min. The inferior properties produced in "as cast" material compared with previously heat treated material can be traced to the greater amount of "burning" of "as cast" material when heated above 720° F. A comparison of Figs. 5 and 6 shows the extreme "burning" of "as cast" material heated to 750° F. and the almost complete absence of such "burning" in previously heat treated material. The dark areas are voids and indicate severity of "burning."

The absence of "burning" in Fig. 5 results from the more rapid solution of the low melting constituents in previously heat treated material.

Samples of previously heat treated and aged materials were removed from the solution furnace at various temperatures during rapid heating for re-solution treatment. These results indicate the lamellar precipitate is practically completely redissolved by the time the sample has attained a temperature of 650° F.

From the foregoing data, the reason for the selection of 725° F. as a solution temperature is apparent. Higher temperatures promote "burning" of the "as cast" alloy with consequent loss of properties. Lower temperatures will prolong the time required and possibly prohibit the complete solution of the "beta."

Aging Cycle

Effect of Aging Temperature. In Table VIII are shown the effect of varying aging temperatures on physical properties. It may be seen from these data that no appreciable aging takes place at 250° F. This was borne out by metallographic examination which showed a solution treated structure at the end of 16 hr. aging at 250° F. It should be further noted that 450° F. aging for 16 hr. effects a decrease in ultimate and yield strengths.

There is very little difference between "as cast" and previously solution treated and aged bars.

Effect of Aging Time. Figure 7 shows the aging curves at 350° F. and 450° F. Each point represents the average of 12 bars except on the yield strength curve, where only two values were determined at each aging time indicated. The more rapid aging at 450° F. is to be noted with the rapid decrease in ultimate strength and early increase of yield strength. The possibility of aging for 3 hr. at 450° F. is worthy of continued investigation into other properties such as fatigue strength, impact strength, etc.

Aging at 350° F. was carried out to 160 hr. with no significant changes in properties from those shown at 16 hr. The elongation de-

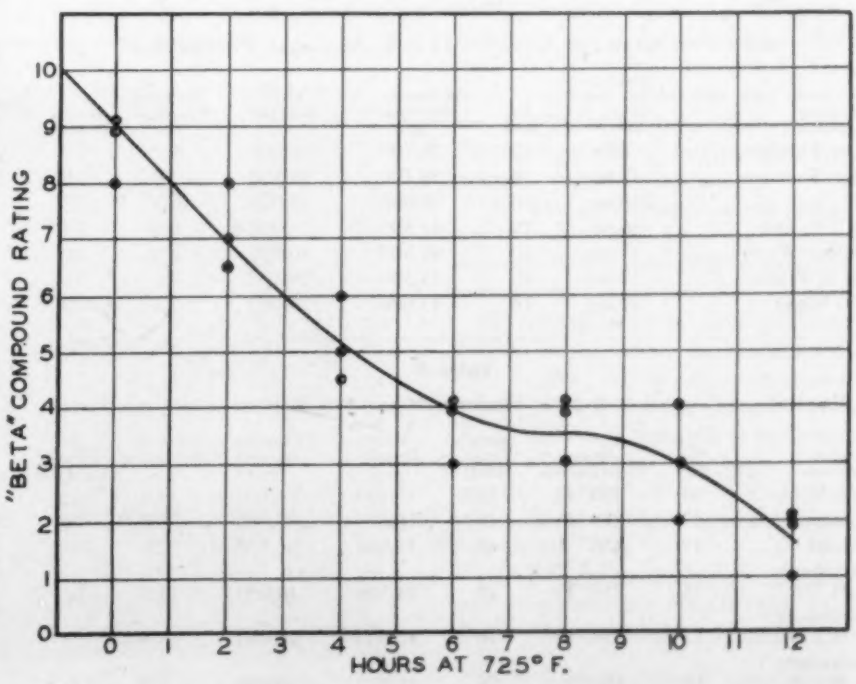


Fig. 2. Effect of Time at Solution Temperature on "Beta" Compound Rating.

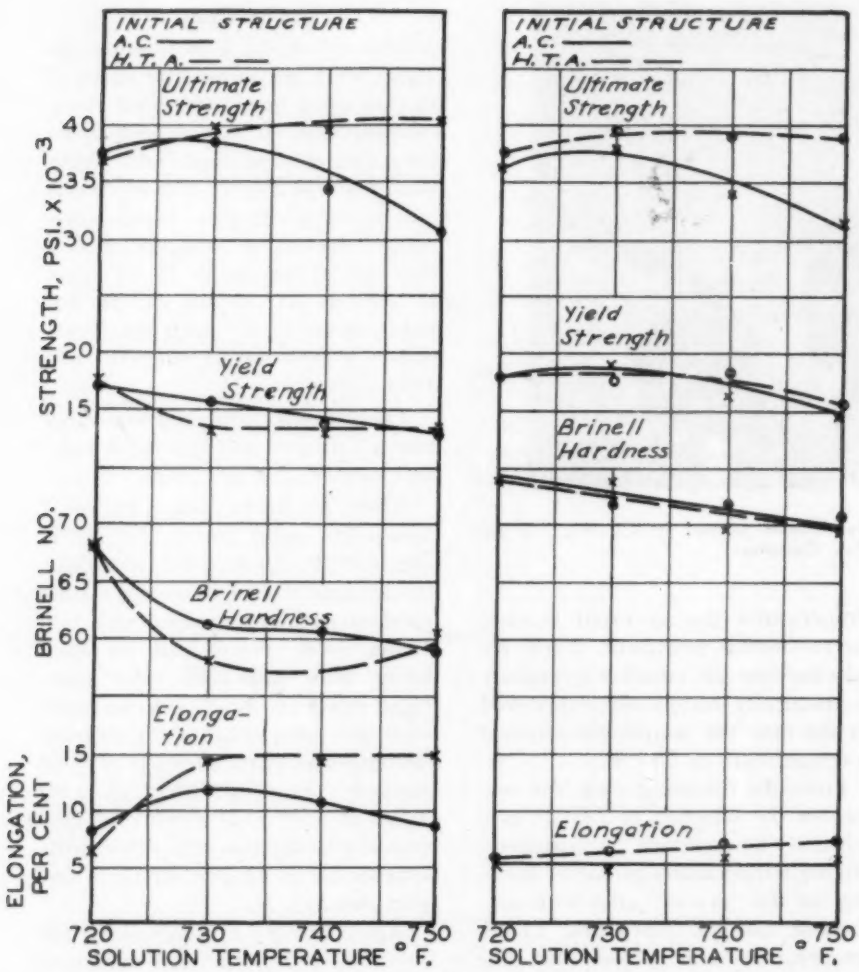


Fig. 3. (Left) Effect of Solution Temperature on H.T. Properties of 6% Al, 3% Zn Magnesium Alloy. Fig. 4. (Right) Effect on H.T.A. Properties.

Table 7

EFFECT OF COOLING RATE ON H.T.A. PHYSICAL PROPERTIES

Cooling Method	*Time to Cool from 725° F. to 250° F.*	*No. Bars*	*Ultimate Strength, psi.*	*Yield Strength, psi.*	*Per Cent Elongation, 2 in.*	*Brinell Hardness*
Slow Furnace.....	8 hr.	13	35,700	18,000	5.7	72
Fast Furnace.....	15 min.	16	38,100	18,500	7.0	70
Air	220 sec.	10	39,000	18,000	6.5	72
140° F. Oil	66 sec.	10	42,800	19,000	8.0	78
Boiling Water	44 sec.	10	43,500	20,000	7.0	80
70° F. Water	32 sec.	10	43,500	19,400	7.5	75
Ice Water	22 sec.	10	43,800	19,800	7.5	79

Table 8

EFFECT OF VARIOUS AGING TEMPERATURES ON PHYSICAL PROPERTIES

Initial Structure	*No. Bars*	*Aging Temperature*	*Aging Time-Hours*	*Yield Strength, psi.*	*Ultimate Strength, psi.*	*Per Cent Elongation, 2 in.*	*Brinell Hardness*
As-cast	14	250° F.	22	15,100	41,600	15.4	63
As-cast	17	350° F.	16	18,500	39,000	6.5	72
As-cast	12	450° F.	16	17,600	36,900	7.0	74
Previously H.T.A.	13	250° F.	22	14,500	40,600	14.5	63
Previously H.T.A.	17	350° F.	16	17,900	39,000	5.9	75
Previously H.T.A.	11	450° F.	16	17,560	38,800	7.3	71

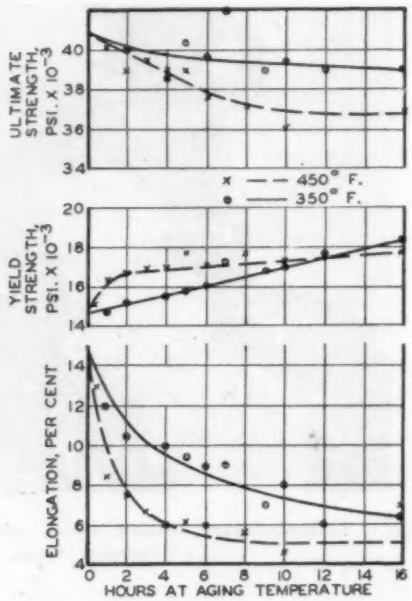


Fig. 7. Aging curves at 350° F. and 450° F. for 6% Al, 3% Zn Magnesium Alloy.

creased to 5 per cent and the yield strength increased to 19,500 psi. with no change in ultimate strength.

In Figure 8 are curves showing the variation in amount of lamellar precipitate with time. It may be ob-

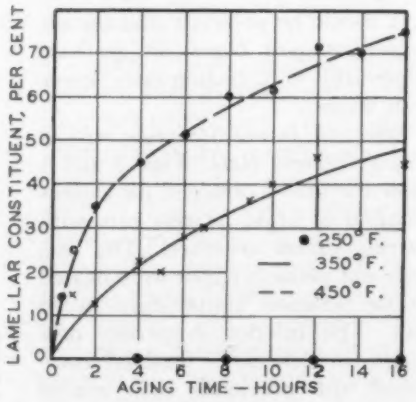


Fig. 8.—Effect of Aging Time on Lamellar Constituent Rating.

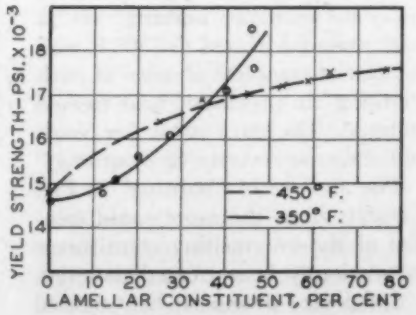


Fig. 9. Effect of Amount of Lamellar Constituent on Yield Strength.

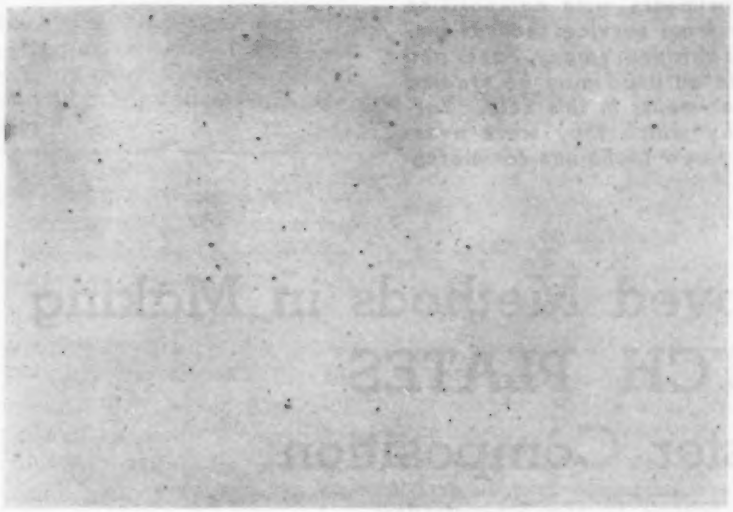


Fig. 5. Previously H.T.A. sample of 6% Al, 3% Zn Magnesium Alloy heated to 750° F. in 20 minutes. Unetched. Note absence of "burning."

Table 9

Effect of Heat Treatment on Dimensional Changes

Section Size	*Dimensional Increase (Inches Per Inch)*			
	Diameter		*Length*	
	H.T.	*H.T.A.*	*H.T.*	*H.T.A.*
1-in. Diameter	0.0002	0.0008	0.0006	0.0007
2-in. Diameter	0.0004	0.0006	0.0004	0.0007
3-in. Diameter	0.0003	0.0009	0.0009	0.0011
Average Increase	0.0003	0.0008	0.0006	0.0008

served the precipitate forms most rapidly at 450° F. and not at all at 250° F. Comparison of Fig. 8 with Fig. 7 shows that the ultimate strength is relatively independent of the amount of lamellar precipitate while yield strength is more directly affected as shown in Fig. 9.

Dimensional Changes during Heat Treatment: A brief study was made of the dimensional changes occurring during heat treatment.

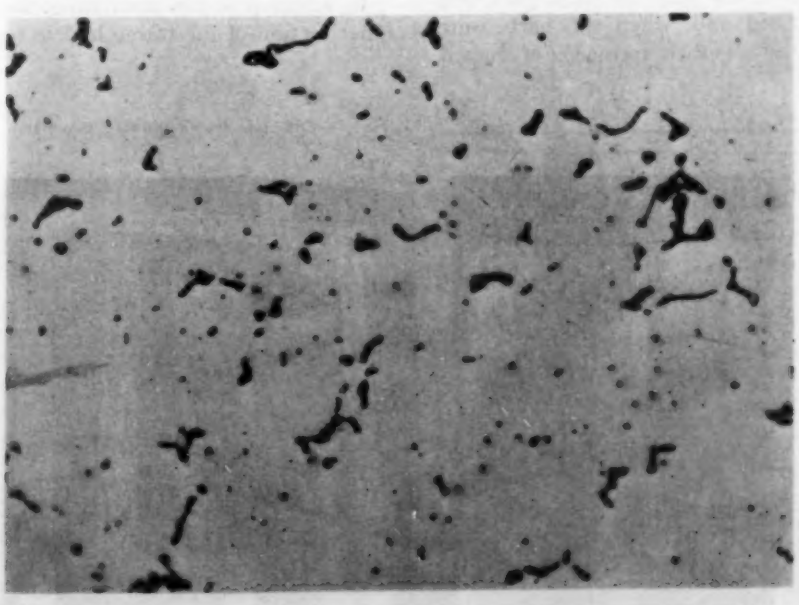


Fig. 6. "As Cast" 6% Al, 3% Zn Magnesium Alloy sample heated to 750° F. in 20 minutes. Unetched. Note evidence of "burning."

One, two and three inch diameter slugs were cast. From these slugs, ¾-in. diameter bars 3 in. long were machined. These bars were then measured in the "as cast" condition, after solution treatment and after solution treating and aging. The results are shown in Table 9.

From these data, it may be observed there is a rather slight growth during both solution treatment and aging. Actual measurements on castings were very erratic. Certain dimensions appeared to become larger while others did not change or in a few cases even decreased. In general, however, there was some growth but the growth in all cases was insignificant when compared to normal foundry tolerances for castings up to 24-in. in diameter.

Conclusions

The following conclusions may be drawn from the investigation for material with a grain size of 0.003 in.-0.005 in. average grain diameter.

(1) Pouring temperatures between 1330° and 1460° F. do not seriously affect static physical properties.

(2) "As cast" material must be slowly preheated to prevent undesirable "burning." Previously heat treated material may be heated more rapidly and to higher temperatures without "burning."

(3) Solution temperatures between 700° F. and 750° F. give similar properties if no "burning" occurs.

(4) Solution times of 12 hr. minimum at 725° F. are required to dissolve the primary compound. The static physical properties are above the usual specification values before the compound is completely dissolved.

(5) Drastic cooling from the solution temperature does not greatly improve static physical properties over air cooled properties.

(6) Aging does not take place at 250° F. in less than 22 hr. Beyond 250° F. the rate of aging increases rapidly with increasing temperature.

(7) Ultimate strength is not seriously affected by the amount of lamellar precipitate formed during aging. Yield strength appears to be directly affected.

(8) Dimensional changes during heat treatment are considerably less than nominal foundry tolerances.

[1]George, P. F., "A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys," A.S.T.M. preprint p. 3 (1944).

• The author has conducted varied experiments with composition match plates and presents a compilation from service records embodying points of interest to every practical foundryman. Facts and figures have been set down—the methods outlined may be studied in relation to individual methods and experiments in this field. Various problems encountered—the means by which they were overcome—and the development of an entirely new technique for match-plate production are described.

Describes Improved Methods in Making MATCH PLATES of Plaster Composition

By C. C. Brisbois, Foundry Superintendent,
Robert Mitchell Co., Ltd., Montreal, Que., Canada

UPON the outbreak of war, the demand for castings was greatly increased. The development of means for producing A-1 quality castings in great quantities in the shortest possible time was of prime importance.

Not only did the quantity and quality far exceed prewar demands, but the designs of the castings were far more intricate in many cases than anything that had been produced before the war. This intricacy of pattern added to the urgency of the problem of their production, and at that time few alternatives were offered to the foundries with which to meet the situation.

All-Aluminum Plate

The all-aluminum plate with mounted patterns proved to be too slow, requiring infinite care in the mounting and cleaning processes. Mounting, cleaning, and finishing called for skilled labor, the shortage of which was even at that early stage beginning to make itself felt. Aluminum-cast plates were vetoed for the same reasons.

The author had been, through all of his years in the foundry trade, a most persistent advocate for composition-cast match plates. Up to that time the cost involved in the making of the frame, and the too frequent loss of the plate itself through breakages, had prohibited extensive use of this medium, and for these reasons it was not highly acclaimed generally. As a consequence, its possibilities were not developed to any great extent and its adaptability to wartime demands was, broadly speaking, in the pioneering stage.

Past experiences served the author well and, when he adopted the compostion-cast match plate for wartime demands, he faced the problem of its development with a great degree of confidence.

Preliminary Methods

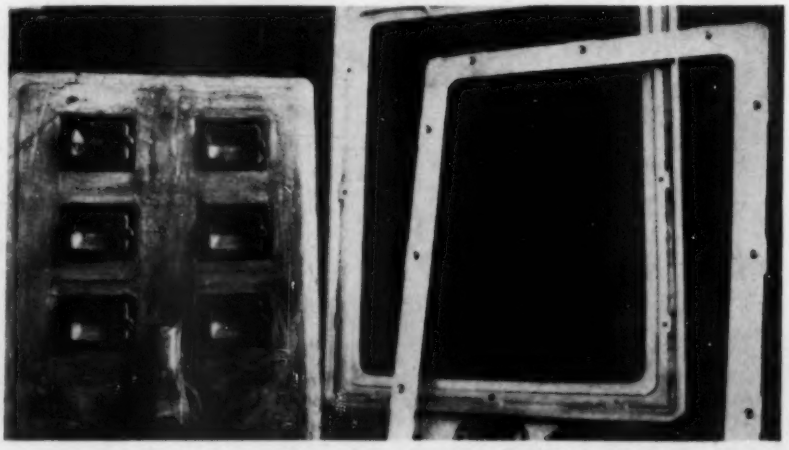
When experiments first started in the author's foundry with plaster composition match plates, it was the general practice to make the frame in two parts—an outer frame into which an inner frame was inserted. The inside edge of each part was bevelled and, when the parts were placed together, formed a V-shaped groove on the inside of the completed frame (Fig. 1).

This groove provided anchorage for the plaster compound when poured into the frame, and the two parts were held together with screws. The entire frame had to be machined, both sections, top and bottom. The inner frame had to be fitted to an exact bearing into the outer frame and onto the groove.

A perfect bearing was essential to prevent any possible flexing between the two sections. Such a flexing, were it present, would cause the plate to crack or break after being in production for a short time, if not before.

In addition to the machining, the inner section of the frame had to be

Fig. 1—Old-style frame showing two parts.



This paper was secured as part of the Program for the 1945 "Year-'Round Foundry Congress" and is sponsored by the Patternmaking Division of A.F.A.

drilled and tapped for fitting into the outer section. The greatest of care had to be exercised here, also, to obtain an even bearing.

The inner section was designed to be removed from the outer section for the purpose of removing the composition plate, which then could be replaced by another. One frame was thus kept continually in circulation, while plates were stored against further requirements, after their first run.

Disadvantages Encountered

It became more and more evident through experience in the use of these frames that the normal life of the plate was shortened by this method. Time prohibited thorough development of this theory, but the fact that a plate would produce from 300 to 500 molds with little trouble so long as it remained in the frame as cast, and that cracking or breaking occurred almost immediately after the plate had once been removed from and replaced into the frame for a second run, was of sufficient significance to warrant suspicion.

It was believed at first that when the plates were replaced in the frame for a second run, an uneven bearing had resulted from the removal of the plate from the frame. In an effort to maintain an even bearing, soft putty, wax or a plastic compound, was often used, but with little improvement of the situation.

The theory that these plates became damaged on the racks when not in use was discredited when it was assured that every care was taken to protect them. A special rack was designed and used for their storage, and a similar but smaller rack was erected in the foundry for their protection during production (Fig. 2).

Each plate was removed from the machine at the end of the day's run and placed in this foundry rack. A trustworthy man was appointed to carry these plates to and from the rack during production, and to the storage rack at the completion of the job. Each plate was carefully examined before each day's production run but, with all these precautionary methods, the trouble recurred with provoking regularity.

To definitely establish causes for cracks or breaks would necessitate a prolonged and careful study of all contributing factors. The author was not concerned with proving his theories at that time, but mainly with developing and improving technique.

New Type Frame Developed

The author's first concern was to cut down or overcome the loss of plates. In support of his theories, the old type two-piece frame was abandoned. In its place he developed an entirely revised one-piece frame (patent applied for), designed primarily to protect the plate against cracking, breaking or other damage.

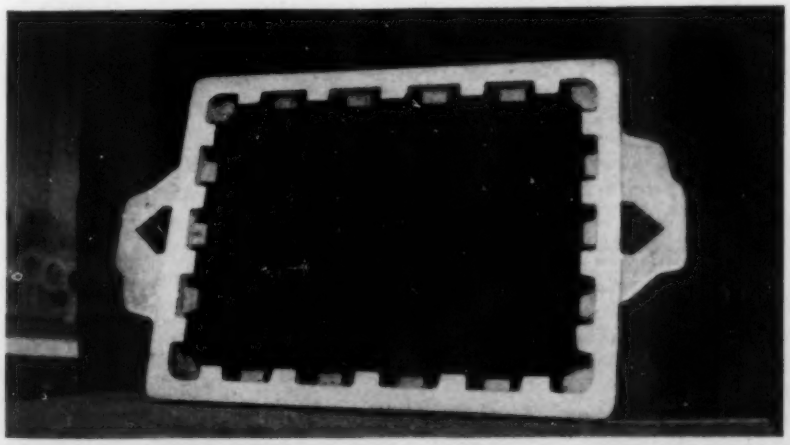
Fig. 2—Specially designed storage rack.

At first glance it may seem that to confine a frame to one particular plate throughout the lifetime of a job would be a costly process, but the author worked on a theory that if a cheaper type of frame could be designed to cut down plate loss, having the advantages of the old type but none of its disadvantages, it would justify itself financially. How sound this theory proved to be will be shown later.

Originally, the two-piece frame had been designed for the purpose of facilitating the mounting of different patterns and to permit the removal of plates and the insertion of others, to cut down the necessity of making too many frames. The labor and machining involved made the use of these frames costly, and the idea was to make one frame do as much work as it could be adapted to.

It is obvious, however, that the saving was in the frame itself; the cost of the patterns, molding of the plate, and storage, remained the same, while the financial loss through damaged plates far exceeded the economical value of the frame. It was logical, therefore, that the first step should be toward developing a low-cost frame having as its pri-

Fig. 3—New type frame made in one piece.



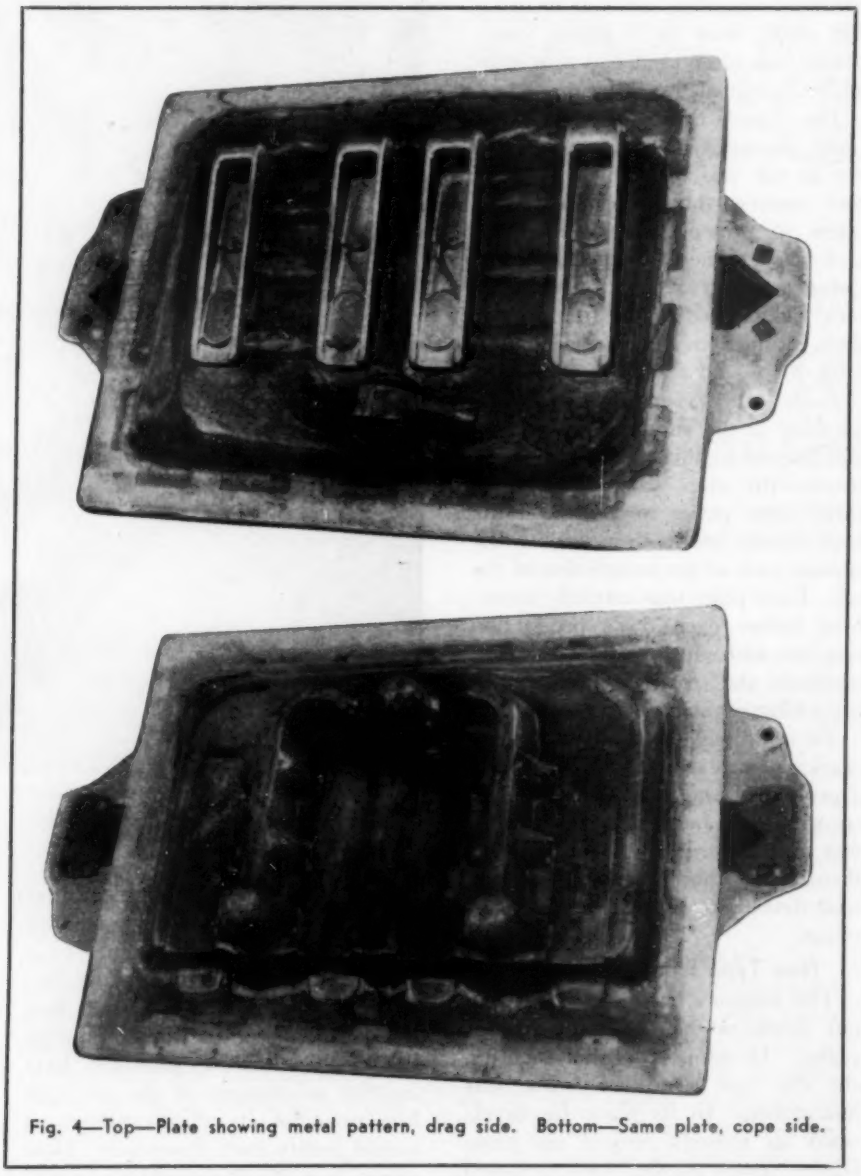


Fig. 4—Top—Plate showing metal pattern, drag side. Bottom—Same plate, cope side.

mary function the protection of the plate against damage.

Frame Casting

Instead of the two-piece, double-molding operation of the old type, the new frame is cast in a single molding operation which draws out of the mold without cores, complete with supporting projections and lift handles (Fig. 3).

Solid projections or teeth about an inch wide are cast flush with the frame at intervals of about 2 in., alternating from bottom to top of the frame. No special care is required to cast these teeth smooth, as a certain amount of roughness will lend further support to the plaster compound in the frame. Steel strips or wires are supported by these teeth for further reinforcement.

The handles are cast like large, V-shaped holes with sufficient clearance to allow insertion of standard V-shaped pin guides. The guides, made of brass and cast to size, require file-finishing only to fit.

Frame Thickness

The thickness of the frame may vary. That is to say, one frame may be 1 in. thick, while another may be ¾ in. thick, but whatever the thickness of the individual frame, it must be maintained throughout the entire frame.

The 1-in. frame is preferable since it will support the minimum amount of compound with the maximum of strength. Approximately 1/16-in. machining is necessary on the back and front of the frame. As these surfaces are perfectly flat, the machining process is very simple and inexpensive.

Frame Molding

The molding of the new type frame is a very simple operation throughout, involving a minimum of unskilled finishing labor. Eliminating as it does the necessity for skilled labor, this feature is a recognizable advantage over the old type frame.

Further, this economical feature of the new type frame is not confined to the molding operation alone, nor does the fact that it is confined to one job for a longer period of time detract from its productive value.

The life of the new type frame is as long, if not longer, than that of the old type, and will go on through production of other plates for many years. Both the old and new type of frame are cast in aluminum. Wear and tear being equal, there is nothing to indicate that the normal life of each type is not equal.

As with the old two-piece type, the new one-piece frame becomes available for another plate immediately the production schedule of one plate is completed. The plaster compound is broken up, all patterns carefully removed and cleaned, stored or returned to the customer, as the case may be, and the frame is ready for another job.

The saving effected through the use of the new type may not at first be apparent, but, failing a comparative cost study through the actual use of both types of frames, which the urgency of the need prohibited at that time, the economical potentialities of the new type cannot fail to be recognized. Service records indicate that, through the preservation of plates for the lifetime of the job, production costs have been cut as much as 50 per cent or more.

Comparative Mold Production

To emphasize this point, plates which have produced 10,000 and more molds, using the new type one-piece frame, are in the storage racks of the author's foundry, still in excellent productive condition. The highest quantity on the records of molds produced off one plate in one run, using the old type two-piece frame, is 1000.

These figures are given to emphasize the value of plate protection. This does not prove that the plate which produced 1000 molds while in the old type frame would not

have gone on through production of 2000 or even 5000 molds, if left in the frame as cast. The point indicated here is that 1000 molds is the highest quantity of molds ever produced in the author's experience without removing the plate from its original frame.

Once the plate had been removed from the frame and replaced for a second run, the plate broke or cracked and was useless for further runs. How many plates would have had to be remade to produce as many as 10,000 molds by this method, is a matter of conjecture.

The point is that a plate in the new type frame will produce 10,000 and more molds with very little, if any, further expense than the initial cost of making the plate up, and still be in good working condition. Over and above the reduced molding cost of the new frame, this feature further reduces actual production costs many times over.

Wires Still Used

While wires are still used to reinforce the plaster compound, as with the two-piece frame, this practice is not so favored with the new frame. The use of wire, except where absolutely necessary, is not highly recommended as a general practice.

When wire is used, care must be taken to determine the exact size suitable for the job. Too thin a wire has a tendency to "spring" and too thick a wire requires more compound to cover and, consequently, a plate too thick and too clumsy to handle. Costs of plates being based on weights, the cost is proportionately higher. In both cases, the plate is weakened instead of being strengthened.

It was noted that cracks most frequently occurred directly over the wire when thick wire was used. This would indicate that there was not sufficient compound in the frame to permit of a thick enough layer over the wire.

Even with the 1-in. frame, which will support the maximum amount of compound, this tendency was apparent. To make a thicker frame to accommodate a sufficient quantity to cover a thick wire, would result in a plate too awkward, too costly, and too heavy to handle with proficiency.

This tendency was not apparent when using thin wires, but the compound would more frequently break away from the sides of the frame. Had time permitted a more detailed and lengthy investigation of the behavior of wires, more definite and interesting data might have been discovered as to cause and effect.

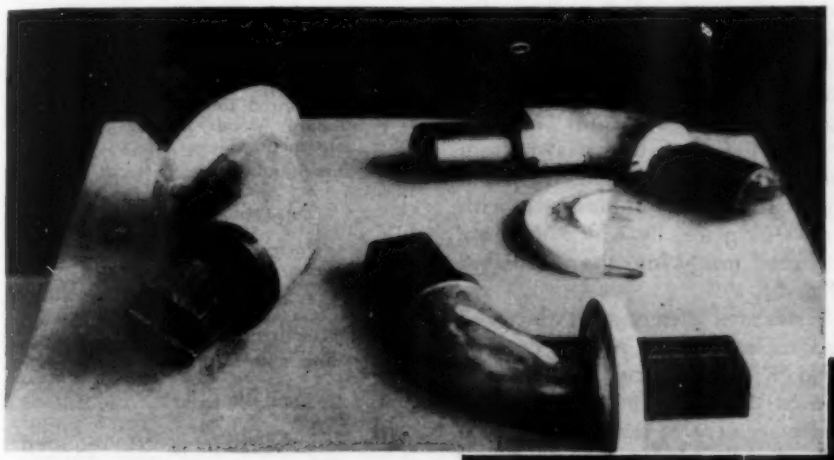


Fig. 5—Above—Elbow pattern showing loose flanges cast in aluminum.

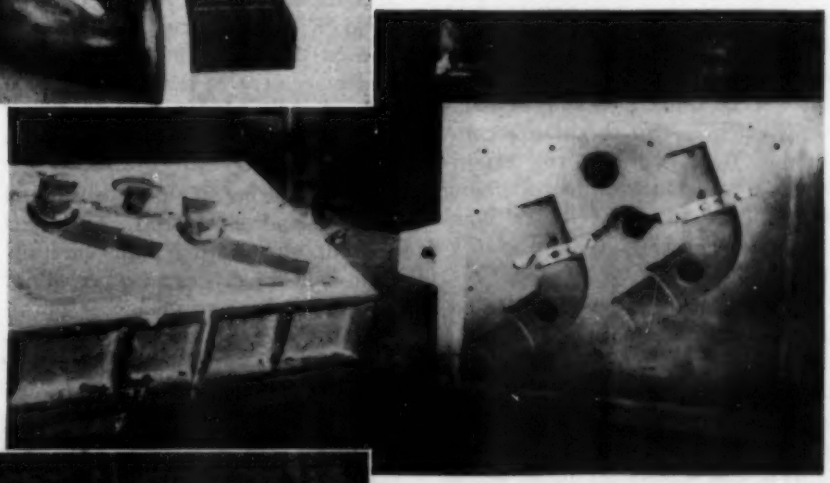


Fig. 6—Right—Mold with flanges in place, anchored firmly to compound.

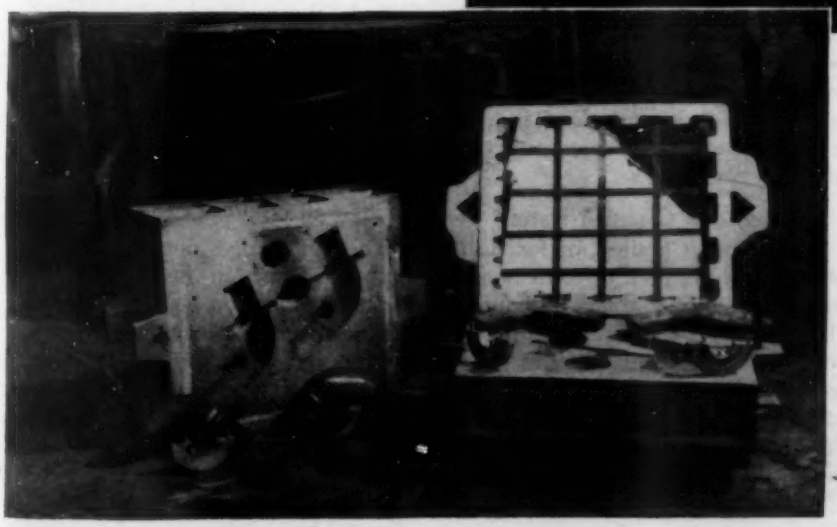


Fig. 7—Below—Mold all ready for closing.

Steel Strips

As it was, theory again carried the day and, in an effort to overcome these disadvantages, wires were replaced almost exclusively by metal strips. Previous experiments had proved most successful and, with the abandonment of wires, time was

now devoted to the development of proper technique for the use of strips.

Mild steel was found to be the most suitable. Standard type of steel strips used was No. 10 U.S.S. Standard (approx. ⅛ in. x ½ in.) length cut to size. Whenever possible, requirements are confined to the No. 10 steel.

All strips are sandblasted before use, to insure a very clean surface so that the compound will stick evenly and thoroughly. Strips are placed at strategic points in the frame, criss-cross fashion, and anchored firmly into place on the teeth with wire or nails. In complicated patterns, steel strips may be bent to follow the contour of the pattern.

Technique of Combining Metal and Plaster

The author does not contend that all patterns can be produced from match plates. In certain types of pattern it is not possible to utilize this medium. Again, certain types of pattern cannot be cast solid in plaster compound with practicability.

For instance, in the case of a pattern having bosses, ribs, or thin sections projecting on one side only, it was found that such parts were liable to be broken, nicked, or damaged, when cast in the plaster compound. With such patterns, experiments were conducted in combining aluminum with the plaster compound, and the results were gratifying (Fig. 4).

The technique was simple. First, solid patterns were cast in aluminum from master patterns. The side of the patterns having ribs, thin parts, or bosses, was placed in the drag, and the opposite side drilled and tapped and screws set in to act as anchors to the cope.

Anchoring Patterns

Patterns were left in the mold when pouring the plate. The finished plate showed the cope in solid compound and the drag the metal patterns, firmly anchored into the compound on the cope, projecting clear above the plate. The metal patterns were proof against breakage or other damage (Fig. 4).

The size of the patterns determines the size of the screws to be used. The average size is No. 10-32th. x ¾ in. The largest used by the author are 24th. x ¼ in. It was found that flathead steel machine screws were the most adaptable to requirements.

Fig. 8—Right—Cleaning the plate.

Elbow Pattern

To illustrate this method to better advantage, the author presents for example an elbow pattern having flanges on one end. These flanges extend above the main body of the pattern and there is danger of their breaking if cast solid in plaster compound.

A combination split wood and metal pattern is first made. In other words, the body of the elbow, including coreprints, is made of wood and the flanges are cast in aluminum, left loose, and recessed in the body of the wood pattern (Fig. 5).

After the pattern is drawn from the sand, the loose flanges are put back into their impressions with screws in place, by which they are anchored firmly into the compound (Fig. 6).

Gates are then cut in the sand and risers or vents indicated. The mold is finished and the frame is laid on the box joint. The number and placement of steel strips is then determined and the strips anchored into place. The mold is then ready for closing (Fig. 7).

After pouring, the plate is brushed and all sand cleaned off. The risers are cut off and the plate carefully examined for cracks or other minor defects, such as shrinkage or porosity. If any such are apparent, repairs are made immediately, while the compound is still wet. Left-over compound is used for this patching operation.

The plate is then sent into the pattern shop where it is put aside to dry. Approximately 5 hr. is sufficient drying time, and plates should be allowed to dry at room temperature for best results.

Drying and Cleaning Plates

When time is limited, or for rush jobs, plates have been dried by hooking them up over steam radiators. This will dry a plate sufficiently for working in approximately 2 hr., but except where unavoidable this practice is not recommended. After the plate is dry, finishing girls clean up and shellac the whole plate (Fig. 8).

The following comparative table, derived from service records, demonstrates conclusively the time saved by the composition match plate over the all-aluminum plate.

Combination Metal and Plaster Composition Plate	
Time required to make two combination wood patterns with loose metal flanges, hr.	30
Cleaning and fitting patterns, hr.	7
Total time, hr.	37
Metal Patterns Set on Aluminum Plate	
Time required to make wood master pattern and two aluminum split patterns, hr.	40
Cleaning and fitting patterns, hr.	24
Total time, hr.	64

Core boxes, dryers, etc., required the same time in both cases and are, therefore, not shown on the table. There is a straight 42 per cent saving in hours, but time is not the only saving. A monetary saving is also effected, not only by cutting down the hours but by employing unskilled finishing labor.

Plaster vs. Aluminum Plates

With the plaster composition plate, finishing girls at a lower wage will do the required finishing with efficiency, but skilled labor at a much higher rate of pay is essential for finishing the aluminum plate. It is quite probable that, in most cases, the difference in the wage scale between these two classes of labor might well be 50 per cent.

The author does not wish to convey the idea that he believes the plaster composition plate or the combination of metal and composition plate better than the all-aluminum plate. He does wish to emphasize the fact that they are more flexible to work with, less expensive and faster, and will produce as good a casting as the aluminum plate, which

is, after all, the most important factor. Thousands of castings have been produced off these combination plates—castings with tolerances as close as 0.015 to 0.031 in. in the Class I (to be X-rayed) category.

Alterations

After the plate has been made, alterations to gates or patterns, should any be necessary, can be done with much more speed and facility on the plaster composition plate than is possible on the aluminum cast plate.

For instance, should the gates need to be changed, they are simply cut off, small cigar box nails inserted to act as an anchor for the compound, new gates shaped to the required size in clay and the compound poured. Whey dry, the new gates are trimmed and smoothed off with a chisel and the plate is ready for production.

Should patterns require to be built up 1/16 in. or ⅛ in. or less, very small nails are inserted for anchors and compound added and built up to more than the required size. After the compound is dry, it is trimmed down to the necessary size. Compound will adhere to compound with such tenacity that the addition will not be discernible. A smooth, clean and permanent job is the result.

Every patternmaker knows what a job it is to build up a pattern on an aluminum-cast plate. First, a brass or aluminum sheet of the required thickness must be screwed or riveted onto the pattern. Lead must be worked into and over the screws or rivets to insure a perfectly smooth finish. A great deal of time and care are required to trim the addition down to the right size to attain a smooth and even surface. At best, in most cases, the result is a patch-up job.

Conclusion

In conclusion, the author relates an actual incident whereby the substantial saving which can be attained through the utilization of plaster composition plates, can be carried on through production in the foundry to the customer outside the foundry.

A quotation was solicited on a certain job. It was a small job and a short run, but it was important and it was urgent, as even the smallest jobs are in wartime. At the same time, it was not worthwhile to the customer to put too much money into the job. Solid patterns were available, and it was suggested to the customer that these be used to cast on a plaster composition plate.

The customer immediately protested the cost of plates, but when it was pointed out to him that the cost of a plate in plaster compound would be approximately a third less than that of an all-aluminum plate, while at the same time patterns would be preserved and returned intact at the completion of the job, the proposition was accepted with alacrity.

The advantage of this proposition was that the patterns could be returned intact to the customer at the completion of the job, but of equal importance was the small sum of money involved, the facility of production, and last but not least, the speedy delivery promised.

Further, should additional castings off this plate be required at some future date but with some alterations necessary to the patterns, no great financial loss would have been incurred by the removal of the patterns from the plate, involving the breaking up of the compound only.

Had these patterns been mounted on an aluminum plate, alterations to patterns would have resulted in a much greater financial loss, or had the old type two-piece frame not been superseded by the more economical, more facile and speedier one-piece type, this gratifying and purposeful suggestion could not have been made available to the customer.

This is only one of thousands of such demands which we have been called upon to meet during wartime, but unlike the beginning, a medium by which such demands can be met and fulfilled is now at our disposal.

Acknowledgment

Permission to prepare this subject for presentation was granted to the author by his principals, the Robert Mitchell Co., Ltd., to whom he expresses his thanks and his appreciation for their cooperation during the development of his subject.

Special Brick Shapes for CUPOLA REFRACTORIES

By H. M. Hazeltine,
Fremont Foundry Co., Fremont, Ohio

• Over a period of years, considerable difficulty had been experienced in cupola operations at the author's foundry because of tap hole, trough, slagging spout and cupola well refractory failures. The use of fire brick shapes, specially designed for particular applications, eliminated the refractory troubles and made possible substantial operating economies.

A 9 in. straight fire brick with a ¾-in. hole located 2 in. from the end was used for the tap hole. This brick was placed in a vertical position and held with stiff bott mud made of fireclay, and this formed the breast.

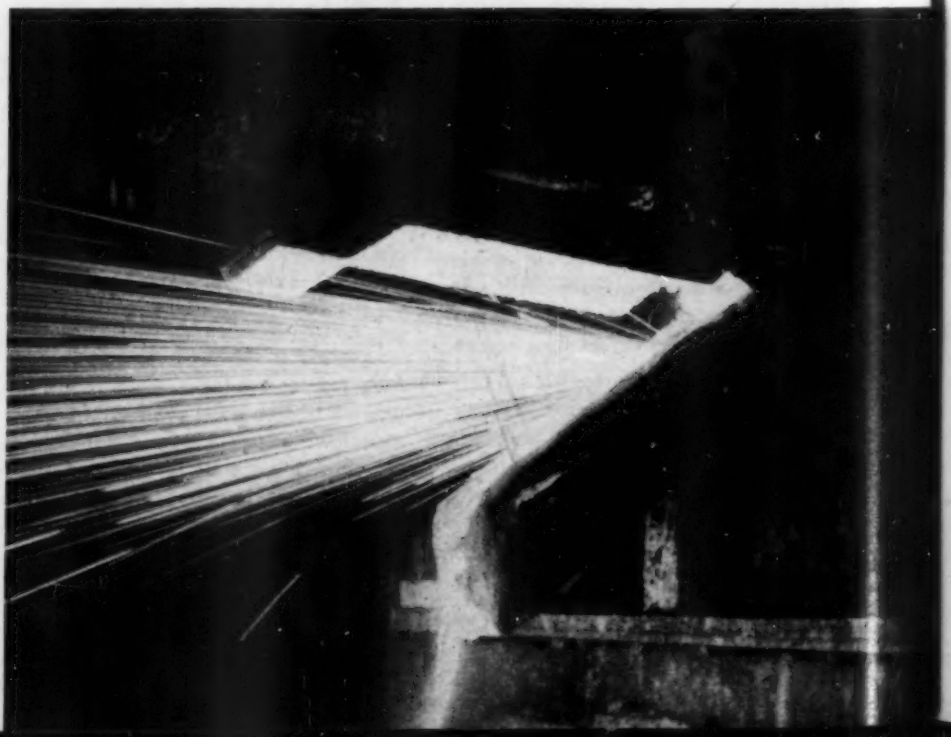
Approximately one hour of more or less skilled labor was required for the proper installation of this tap hole brick. The whole set-up was never very satisfactory at the best, and on long heats would cause more or less trouble.

Twelve years ago a wooden pattern that embodied the tap hole brick and the breast all in one piece was made up. This pattern was submitted to a fire brick supplier with the request that it be duplicated in a fire brick shape. Thirty days later ten samples were received, and they were perfect in every detail. The ¾-in. hole was just right. The quality of the brick was exceptionally good, and this tap hole brick has been used continuously since that time with no trouble of any kind.

It has definitely proved its merits in many ways. It is safe and economical; it can be installed in a few minutes and requires no special skill. It is almost indestructible. This brick is held in place with plastic ramming refractory.

The cupolas are equipped with a steel trough 4 ft. long, 12 in. wide and 10 in. high. This trough was lined with fire brick and daubing mud, forming a runway for the molten metal to flow from the cupola into a receptacle. The trough lining was not very satisfactory, as trouble was experienced on long heats. Each day the trough had to be chipped out and repaired, an expensive operation, so the question was asked, "Why could not this be a brick tile of given length and width—one that could be laid in lengths and form the trough with the proper contour, thus making a valley for the molten metal to flow from the cupola?" The matter was referred to a fire brick supplier, and a special trough tile 13 in. long, 7 in. wide and 7 in. high was made. These are laid in four lengths, bedded in soft, plastic fire clay, and held in place with 9 in. straight brick on the sides. It requires just a few minutes to build the entire trough, and anyone can do this work as there is nothing complicated about it. The life of these trough tile in continuous use will vary from 4 to 6 months, depending upon the care taken with them. To prolong the life of these trough tile, a ½-in. layer of plastic ramming refractory rammed in the bottom contour of the tile is used. It takes just a few minutes each day to do this, and it protects the joints where the tile are placed together. It is surprising how easily this layer of plastic ramming refractory can be scaled off the

Fig. 1—Cupola slag spout showing specially designed refractory cover in raised position.



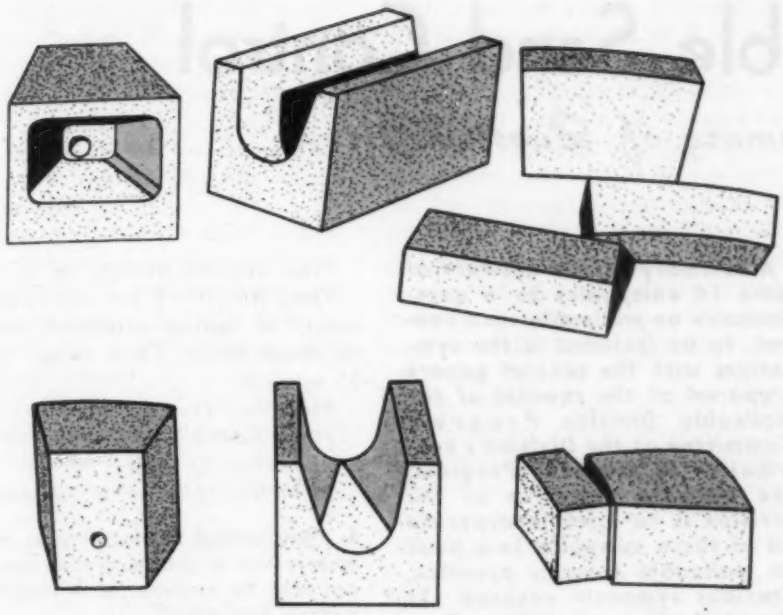


Fig. 2—Sketches of specially designed cupola refractory bricks.

next morning after the heat. This leaves a clean trough, free of all slag that had formed during the heat. When the factors of time saved, safety, convenience and durability are considered, the special trough tile proves to be a profitable investment.

The next brick of special design to be made up was a 72x77 circle brick, which is used as a face brick in the well of the cupola below the tuyeres. Previously, 1¼-in. splits placed against the shell of the cupola, and then 72x84 cupola blocks, which were faced off with more 1¼-in. splits, had been used. The life of this facing was about 2 weeks, and it would then have to be replaced. Quite often the slag and iron had destroyed these splits, and removing them would cause damage to the blocks, making an uneven contour in the lining. In relining the cupola every 6 months, the entire base of the well had to be replaced, causing extra work and expense.

Since using the new 72x77 curved brick for facing, all of this previous trouble has been eliminated. These brick will last in continuous service for from 6 to 8 weeks. To remove and replace these brick requires only 30 minutes, and they preserve the main base of the well indefinitely.

The author wishes to state here that "a refractory is only as good as the bond that holds it." Slag and molten metal will attack the joints and, unless care is used in selecting a good bonding material, the life of the refractory will be nil.

Cupola Slag Spout

A cast iron cover was used for the slag spout. The entire cover was of gray iron and the life would vary considerably. The top of the cover would burn through, and this would occur during the heat, causing much delay and inconvenience. The trouble was overcome by having a cover made with an open top and a special brick tile to fit the opening. This fire brick tile cover has proved to be a success in every way. The life of these covers is about 6 weeks. They are held in place with a steel bar fitted on stud bolts on each end of the cast frame and secured with wing nuts, which has proved to be an ideal arrangement. The cover has eliminated all of the sparks and mineral wool coming from the slag hole. To replace these cover tile takes only 60 seconds.

All of these brick are of special design, each has its own function and they have proved to be far superior to anything that has been previously used.

This paper was secured as part of the Program for the 1945 "Year-'Round Foundry Congress" and is sponsored by the Refractories Committee of A.F.A.

Malleable Sand Control

Summary of Questionnaire

TWELVE questions, designed to give a broad picture of malleable sand control practices, are answered by 14 plants. The reports given by all plants are listed under each question.

1. Type of castings produced.

Plant No. 1—Tractor, light and heavy duty trucks, agricultural implements including chain links and roller bearing ends, and Ordnance castings.

Plant No. 2—Automotive castings such as large housings weighing up to 80 lb. down to very small castings. Jack parts, such as gears, bases and frames are also produced.

Plant No. 3—Railway, tank, anti-aircraft, prime mover M-6, etc., of Ordnance.

Plant No. 4—Automotive, agricultural, Ordnance.

Plant No. 5—Pipe fittings.

Plant No. 6—Pipe fittings and small valves.

Plant No. 7—Railroad casting, 80 per cent of production; gear housings for road machines.

Plant No. 8—Railway, agricultural implement, auto accessories, and general miscellaneous.

Plant No. 9—Electrical apparatus.

Plant No. 10—Tractor axle housings, truck differential housings, differential cases, etc.

Plant No. 11—Automobiles, hardware, railway, conveyor castings.

Plant No. 12—Malleable chain and job castings.

Plant No. 13—Ordnance work, truck, tank, railway, hardware, farm implements.

Plant No. 14—Mostly truck and tractor castings.

2. Are the castings produced of a jobbing nature or are they used in the company product?

Plant No. 1—Almost all castings are used in company products.

Plant No. 2—Jack parts are used in the company product. The bulk of work is for outside customers.

Plant No. 3—Jobbing.

Plant No. 4—Of jobbing nature.

• A summary of the answers of some 14 companies to a questionnaire on malleable sand control, to be included in the symposium with the several papers prepared at the request of the Malleable Division Program Committee as the Division's contribution to the 1945 Program. The ultimate objective of the Division is to later incorporate all of these symposia in a book on malleable foundry practice. Previous symposia covered (1) Graphitization of White Cast Iron, (2) Malleable Iron Melting, (3) Gating and Heading.

Plant No. 5—Ninety-five per cent product. Five per cent jobbing.

Plant No. 6—Used in company product.

Plant No. 7—Railroad castings produced for company's end product—brakebeams and freight car door parts. Gear housings and miscellaneous jobbing castings on jobbing scale.

Plant No. 8—Jobbing nature.

Plant No. 9—Company product.

Plant No. 10—Castings produced are company product, cast in production quantities.

Plant No. 11—Both company product and jobbing.

Plant No. 12—Seventy-five per cent used in own product and 25 per cent job castings.

Plant No. 13—Jobbing.

Plant No. 14—Strictly a jobbing foundry.

3. Average weight of castings.

Plant No. 1—Average weight, 0.8-0.9 lb.

Plant No. 2—Great variation in casting weights. Average about 10 lb.

Plant No. 3—Six lb.

Plant No. 4—From 2 to 3 lb.

Plant No. 5—From ½ to 50 lb.

Plant No. 6—One lb.

Plant No. 7—Railway castings average 22 lb. Jobbing castings average 32 lb.

Plant No. 8—Average of 1.5 lb.

Plant No. 9—Average of 4.7 lb.

Plant No. 10—The average weight of castings produced would be about 50 lb. These range from 15 to 65 lb.

Plant No. 11—1½ lb.

Plant No. 12—0.4 lb.

Plant No. 13—7 lb.

Plant No. 14—11.4 lb. (approx.).

4. Are special casting finishes necessary, such as special grade, fine, or can they be medium, or is smoother surface demanded?

Plant No. 1—We need a very smooth finish on chain links, roller bearing ends and many other very small castings. The heavier tractor and truck castings may have a medium finish.

Plant No. 2—Medium finish.

Plant No. 3—A relatively smooth surface is required—all castings varying in degree by the size of the casting.

Plant No. 4—For our general line of work a medium finish is satisfactory. Light work requires a smoother finish.

Plant No. 5—Surface suitable for galvanizing.

Plant No. 6—Fine finish.

Plant No. 7—Railway casting finish, medium; jobbing castings, fine.

Plant No. 8—Some few jobs require a finish smoother than that obtained by wheelabrator cleaning. and they are usually handled with sand blast using grit.

Plant No. 9—Medium finish.

Plant No. 10—No special finish or smoothness is required.

Plant No. 11—Medium finish.

Plant No. 12—25 per cent fine finish, 75 per cent medium finish.

Plant No. 13—Casting finish is medium on most work; just a few jobs need a special finish.

Plant No. 14—Medium surface conditions prevail.

5. Does plant have sand handling equipment, and is the sand supplied to the molders by continuous system, periodic or by heaps?

Plant No. 1—We use a sand sling-

er on one large floor but all squeezers and machine molds are worked from heaps.

Plant No. 2—Molders are supplied by heaps.

Plant No. 3—A No. 1½ muller type pan mixer. By the wheelbarrow full.

Plant No. 4—No. Sand is supplied to molders by heaps.

Plant No. 5—Continuous sand handling.

Plant No. 6—Continuous sand handling system.

Plant No. 7—Sand reconditioning available; facing sand prepared and furnished to molders by trucking. Some heap sands on side floors.

Plant No. 8—No.

Plant No. 9—No sand handling equipment.

Plant No. 10—Sand is supplied to the molders by a continuous system.

Plant No. 11—Yes, continuous system.

Plant No. 12—Individual heaps only.

Plant No. 13—Two continuous systems (slinger and hopper lines); one-third of plant operates by heaps and facing.

Plant No. 14—No. 1 and No. 2 foundries are equipped with continuous sand handling systems. No. 3 foundry, which is light bench work, is worked from heaps cut back to benches with sand cutter.

6. Give some explanation of equipment used for sand processing.

Plant No. 1—We have four gasoline motor driven sand cutters, three sand slingers used as sand conditioners, and six portable type sand conditioners.

Plant No. 2—Heap sand is first put through aerator, after wetting, and then taken in boxes to facing mill where it is put through screen and falls on belt which carries it over magnet to remove metal. Sand falls into skip hoist where correct amount of new sand and sea coal is added. The measurement is volumetric. When one skip hoist has enough old sand, the old sand is run into another. The skip hoist raises sand in the two muller-type, pan mixers where southern and western bentonite and water are added. The finished facing goes into box which is transported by truck to the molding floor.

Plant No. 3—For each wheelbarrow full of facing delivered to the molders, about ¾ of a wheelbarrow of his heap sand is brought back to the facing room, where it is dumped on a screen to remove any chills or particles of iron in the sand; and then about 70 per cent of this returned screened sand is dumped into lift bucket on the No. 1½ muller-type pan mixer, and to it is added new opener sand, new molding sand, southern bentonite, and sea coal according to the type of facing desired, and then mulled in the mill for 5 min., at which time it is properly tempered with water and then discharged through aerator attachment from outlet of mill into wheelbarrow, and then dispatched to molders needing it.

Plant No. 4—Heaps are cut nightly with a sandcutter. Floors having cores and chills are riddled. A muller-type, pan mixer is used for mulling facing sand.

Plant No. 5—Elevated from floor through rotary riddle, tempered, through paddle mill onto cooling belt, then through revivifier to distributing conveyor to molders' hoppers.

Plant No. 6—Riddles, pug mill, cooling belt and aerators.

Plant No. 7—Used sand is brought to floor grating, dumped at night and elevated to storage bins. Batch type preparation in two muller-type, pan mixers produces the required facing sands stored in overhead bins from which withdrawals are made by truck to the respective molding floors.

Plant No. 8—Sand reconditioned in muller-type, pan mixer after addition of illite-type clay.

Plant No. 9—Facing used on all patterns. Mixed in muller and put through aerator.

Plant No. 10—Spill and shakeout sand return to storage bins. This is then fed with new sand addition to mulling machines. After mulling, sand is delivered to hoppers above machines or slingers.

Plant No. 11—Return sand from the shaker to a dry sand storage bin, then mixed in sand muller, where clay, sea coal and water are added. A prepared sand bin holds some 50 tons. This prepared sand goes through an aerator and is carried on belts to conveyor lines where it is ploughed off into hoppers for use by the molders as may be required.

Plant No. 12—A muller-type, pan mixer for facing sands only.

Plant No. 13—Two 3000-lb. muller-type, pan mixers produce a facing-backing sand for a continuous slinger mold conveyor line, and a continuous hopper mold conveyor line (each a separate unit). One-third of plant operates by facing and heaps.

Plant No. 14—In No. 1 and No. 2 foundries, sand is supplied to molders in bins above their machines. Sand is mixed in a high speed muller and delivered by means of elevator to overhead conveyor belt and discharged into bins. Sand is fed to molds from bins through conventional clam shell spout.

7. Does plant have own sand control laboratory? If feasible, give some description of sand control equipment as to type.

Plant No. 1—We have our own sand control laboratory. Moisture teller, sand ramming apparatus, permeability apparatus and hand operated dead-weight type apparatus to determine compressive green and dry strength of molding sands.

Plant No. 2—The metallurgical laboratory takes sand tests. Equipment includes motor driven sand strength machine, permeability meter, sand rammer, moisture teller and bomb-type moisture tester. With the latter type apparatus, the moisture is determined by the pressure of acetylene gas on a pressure gauge calibrated in percentage moisture. Calcium carbide is added to the sample. We prefer this apparatus because of speed and convenience.

Plant No. 3—Yes. We use the green bond compression machine, permeability meter, bomb-type moisture tester and U. S. standard screens.

Plant No. 4—Yes. We use moisture teller, sand rammer, permeability meter and strength machine.

Plant No. 5—Control moisture, permeability, green and dry shear, compression and fineness.

Plant No. 6—Foundry has sand control laboratory with proper equipment.

Plant No. 7—Sand control equipment available and utilized in part for sand control. Equipment consists of specimen rammer, permeability meter, moisture teller, strength machine.

Plant No. 8—Laboratory runs per-

meability, dry and green strength, moisture from samples taken from heaps, usually every other day. Additions are made as necessary to maintain required permeability and dry strength.

Plant No. 9—Yes. Moisture, permeability and green strength.

Plant No. 10—Foundry does have sand control laboratory. For green strength and permeability the usual equipment is used. For moisture determinations, a carbide determinator is used. A cement tester is used for core tensiles and a dilatometer is used for hot properties.

Plant No. 11—Yes. Moisture tester, bond-shear machine, permeability machine, muffle furnace, core baking oven, clay wash, core gas determinator.

Plant No. 12—We have sand control laboratory equipped as follows: moisture teller, sand rammer, core dryer, permeability meter, motor operated strength tester.

Plant No. 13—Yes. Moisture teller, bomb-type moisture tester, rammer mounted on wooden pedestal, permeability meter, strength machine, flowability meter, deformation meter, small oven for dry bond testing, and screen series and shaker.

Plant No. 14—We have sand control laboratory. Sand is checked every half hour for moisture, permeability, green compression, and deflection. Sieve tests are taken once a week, or oftener if necessary.

8. Does plant have specifications for buying sands? If so, give examples.

Plant No. 1—We purchase standard grades of natural bonded molding silica (washed) and Lake sands, common in this district which have proven satisfactory for our facings and heaps, taking into consideration the conditions our sand heaps retain by their additions.

Plant No. 2—The following are typical sand analysis:

	Sand, per cent		
Mesh	*Juniata Bank*	*Bonded Silica*	*Michigan City*
30	....	.....	.....
40	....	2	.....
50	1.1	33	.....
70	2.0	45	.....
100	37.2	17	.....
140	40.2	3	.....
200	17.6	.....	.....
270	1.5	.....	.....
Pan	0.4	.....	.....
Clay	0.8	None	.....
Grain Fineness	97	51	50–52
Base Permeability	45	155	.....

Plant No. 3—No, but are now in process of setting them up.

Plant No. 4—Sand is purchased by name and grade thus: South Y Heavy; Helmick No. 14; Silica sand 1F; Vassar bank sand. We make our own heap sand mixtures from above sands, adding fire clays for bond.

Plant No. 5—Specification calls for not over 8 per cent moisture in car. A.F.A. fineness number and clay content.

Plant No. 6—No natural molding sand bought; use synthetic molding sand.

Plant No. 7—Yes, but incomplete.

Plant No. 8—In our purchase of naturally bonded sands we try to secure a sand having the permeability needed with as high a bond as available, having in mind the heat resisting properties of the particular sand.

Plant No. 9—Do not have our own specifications. Buy from samples based on tests.

Plant No. 10—Plant has specifications for buying sand.

Bank Sand. The material desired is a sand that is suitable for use in making molds and cores.

(1) *Size.* Not less than 15 per cent, nor more than 45 per cent, should remain on the 70-100 mesh screens, balance through 100 mesh.

(2) *Chemical.* This sand should not contain less than 85 per cent SiO_2 (silica) and not more than 6 per cent Al_2O_3.

(3) *General.* This material must be clean, being free from quicksand, roots and all foreign matter.

(4) *Methods of Tests.* Tests will be made in accordance with the A.F.A. standard methods on the original lot furnished at the time contract is made. All subsequent shipments must be of equal or better quality.

Silica Sand. The material desired is a sand known to the foundry trade as a crude silica sand.

(1) The desire is to obtain as uniform rounded grain as possible. On a screen test not less than 80 per cent must remain on the 40 and 70 mesh screens, none remaining on the 10 mesh and not more than 10 per cent passing through a 100 mesh.

(2) *Chemical.* On analysis this sand should show not less than 95 per cent SiO_2 (silica) and not more than 1.5 per cent CaO plus MgO. A highly siliceous sand will be given preference.

(3) *General.* This material must be clean free from roots and all foreign matter.

(4) *Method of Test.* Tests will be made according to the A.F.A. standard methods on the original lot furnished at the time contract is made. All subsequent shipments to be of equal or better quality.

Plant No. 11—Bank Sand Specifications.

Screen No.	Per Cent *Max.*	*Min.*
6	0.0	.....
12	0.0	.....
20	0.05	.....
40	1.5	.....
70	35.0	10.00
100	30.0	15.00
150	35.0	20.00
200	35.0	15.00
270	15.0	.....
Pan	0.5	.....

Chemical Composition. This sand shall have a colloidal content of less than 0.75 per cent and a total alkali content of less than 1.0 per cent; also, free of roots and other foreign material.

Sharp Sand Specifications.

Screen No.	Per Cent *Max.*	*Min.*
6	0.00	.....
12	0.00	.....
20	0.50	.....
40	8.00	.....
70	.....	88.00
100	5.00	.....
150	0.50	.....
200	0.50	.....
270	0.30	.....
Pan	0.20	.....

Chemical Composition. The total colloidal matter plus alkali shall be less than 1 per cent. Sand shall be 98.0 per cent SiO_2.

Plant No. 12—We have sand specifications for purchasing. Some examples are:

Grain size No. 2
Class—D
Clay—9-10 per cent
Grain size No. 1
Class—E
Clay—15 per cent

Plant No. 13—Yes. Shirland and Berlin No. 2—A.F.A. fineness 72.

Plant No. 14—No. Molding sand is purchased as such. A large proportion of core work keeps system supplied.

9. Are specifications or standards available for sand as used in heaps or systems?

Plant No. 1—On the slinger floor we keep the moisture at 3.5-4 per

cent, compressive strength, 4-5 psi., and a permeability of 140-160. This is maintained by Lake sand additions with a colloidal clay, and the facing used has a moisture of 3 to 3.5 per cent, compressive strength, 9½-10 psi., and a permeability of 170-190. The heaps of sand used for medium castings have moisture of 4-5 per cent, a strength of 5-8 psi., depending upon the type of casting to be made, and a permeability of 70-120.

The lighter castings are made with Champion sand from heaps. The moisture is 3.5-4.5 per cent, strength, 3-5 psi., and permeability of 20-35.

Plant No. 2—Average facing sand mixture should run as follows:

Green bond, per cent	5.5 — 7.0
Sea coal, per cent	3.0 — 5.0
Permeability	120 — 140
Moisture, per cent	2.75 — 3.75

Plant No. 3—We endeavor to follow the specifications shown in Table 1 on the various types of facings as they come out of the mill. Raw sand analysis is shown in Table 2.

Plant No. 4—Records are kept of sand mixtures best suited for certain jobs, and sand heaps are built up to these standards.

Plant No. 5—Yes.

Plant No. 6—Yes, green strength, 7 to 8 psi., permeability, 80, moisture, 4 to 5 per cent.

Plant No. 7 — Specifications for sand mixtures are given.

Plant No. 8—No. All our sand is in heaps and treatment for each heap is made suitable for the job running at the time.

Plant No. 9—No.

Plant No. 10—For malleable castings having large amounts of cores the following specifications are used: Green strength, 9-12 psi. Permeability, 150-180. Moisture, 2.2-3.2 per cent. For smaller castings, permeability is 120-150.

Plant No. 11 — Malleable Sand System.

Moisture, per cent	4.4
Permeability	130
Bond, per cent	7.5
Sea coal, per cent	5
Dry strength, psi.	75
Fineness, A.F.A.	55-60
Clay Content, per cent	5
Shear, psi.	2.3

Plant No. 12—Yes. An example—moisture, 6 per cent; permeability, 50; green compression strength, 6.

Plant No. 13—Yes. A screen test is run once a week to aid in checking grain fineness of heaps against basic sand.

Plant No. 14 — No specifications written up.

Table 1

MALLEABLE SAND MIXTURES‡

	Sand Mixtures			
	No. 1	*No. 2*	*No. 3*	*No. 4*
Castings	Light—Small	Medium	Heavy—Large	Extra Heavy—Extra Large
Section, in.	0 to ¼	¼ to ¾	¾ up	¾ up
Weight, lb.	0 to 1	1 to 10	10 to 50	50 up
Specifications				
Permeability	25±10 (31)*	45±15(35)*	60±15 (46)*	75±15 (62)*
Green Strength, psi.	6±1 (6.7)*	7±1 (8.7)*	8±1(8.9)*	8±1(8.3)*
Moisture, per cent	5±0.5(5.5)*	5±0.5(5.5)*	5.5±0.5(5.5)*	5.5±0.5(5.0)*
Sand Mixture, qt.				
Opener—Bank or Ottawa	40** Bank	40 Bank	40 Ottawa	80 Ottawa
New Nash or No. 2 King	24 Nash	24 King	24 No. 2 King	24 No. 2 King
Sea Coal, qt.	6	6	6	6
Binder, qt.	2	3	4	6
Old Heap,† qt.	221	221	221	178

*Numbers in parentheses are representative actuals.
**No. 8 scoop used averages 8 qt.
†To fill remainder of 300-qt. bucket.
‡Average of all four mixtures, percentage composition: Opener, 16.7; new, 8.0; sea coal, 2.0; southern bentonite, 1.3; old heap, 72.0.

10. How are sands checked, daily or periodically? Please give periods of checking.

Plant No. 1 — All facings are checked each day on an a.m. and p.m. basis, with many types checked as to each batch mixed. Certain sections of the heaps are checked each day as are special heaps.

Plant No. 2—A minimum of two tests for each 8-hr. shift are taken.

Plant No. 3 — Once or twice a week the various facings and several of the heaps are checked for permeability, green bond and moisture. If found to be coming outside of specified limits, slight changes are made in mixtures to bring them back.

Plant No. 4—Facing sand, every batch. Heap sand, nightly. Samples are taken from three points, at the two ends and center of heap.

Plant No. 5 — Daily. Complete test in a.m. and p.m.

Plant No. 6—Sands checked hourly.

Plant No. 7—Sands are checked on periodic schedule daily.

Plant No. 8—Usually every other day. Sample taken from three places in heap.

Plant No. 9—Each batch of facing sand is tested for moisture, permeability and green strength.

Plant No. 10—Molding sand is checked on each system every half hour. Core sand is checked daily for tensile properties and weekly for hot properties.

Plant No. 11—Every half hour for moisture, bond and permeability; once a day for sea coal and dry strengths. Fineness and clay content once a week. Shear, once an hour.

Plant No. 12—Checked weekly.

Plant No. 13 — Checked daily,

Table 2

APPROXIMATE ANALYSIS OF RAW SANDS

	No. 2 King	*Vassar Bank*	*Nash*	*Ottawa*
Clay, per cent	22.8	0.4	17.4	Less than 2
A.F.A. Fineness	104	101	133	25 (approx.)
Permeability*	65	110	30	400+
Green Strength*, psi	7	0	6.2	0
Dry Strength*, psi	20	0	21.0	0
Sintering Point, ° F.	2500	.....	.....	.....

*Moisture content, 6 per cent.

morning and afternoon by sand supervisor and assistant.

Plant No. 14—This was answered under No. 7.

11. What are considered essential fundamentals of your sand control work?

Plant No. 1—We consider it essential to our sand control work to keep our permeability and strength within limits. This is tied in very closely with metal and gating practice to eliminate shrinkage and cracks. Another feature in line with permeability is to use a special grade of sea coal which is somewhat coarser than that ordinarily used on heavy gray iron work. Whenever necessary we add pure lake sand to heaps for certain types of castings if previous jobs did require a finer sand. We also make use of the addition of a synthetic sand in addition to heaps of lake sand and clay to keep both strength and permeability.

Plant No. 2—Daily tests on the sand for green compression strength, permeability, moisture, and sea coal are considered essential.

Plant No. 3—(1) Periodic checks for desired specifications. (2) Following-up appearance of castings for smoothness attained. (3) Seeing that laborers do not sidetrack use of screen. (4) Endeavor as much as is practicable, to use old heap sand in making up the different mixtures from heaps on which that type of facing is used. (5) Measure sea coal and binder with containers for that purpose—*not with the scoop.*

Plant No. 4—The setting up of standards of moisture, permeability and strength for all jobs, and strict adherence to these standards, thus eliminating scrap losses due to unsuitably conditioned sand.

Plant No. 5—Keep within permeability limits, moisture control and bond.

Plant No. 6—Hourly checking for standards given in (9).

Plant No. 7—Hot strength of sand.

Plant No. 8—Proper strength to withstand duty in molding and permeability. Heat resisting properties.

Plant No. 9—Moisture, permeability and green strength held within limits prescribed for various classes of work.

Plant No. 10—Essential fundamentals in sand control work are: Green strength for control of hot tears; collapsibility of cores for control of cracks and hot tears; permeability for elimination of blows; and moisture control for eliminating dirt and blows.

Plant No. 11—(1) To control uniform quality of sand. (2) To help control casting defects due to sand troubles. (3) To carry out investigations.

Plant No. 12—Moisture and permeability.

Plant No. 13—A basic sand suited to the type of castings produced; moisture control, permeability control, strength control.

Plant No. 14—Permeability of over 80. Moisture, 5.0 per cent or under.

12. Give any special information as to sand control work in keeping with your policy.

Plant No. 1—The sand control work is followed very closely by a woman employee who makes reports daily to the furnace foreman and to the foundry management of sand and facings used on the first shift. We also have a foreman whose duties are only to watch and check all facings and heaps on the second and third shifts.

Plant No. 2—We consider sufficient mulling very important. Because of the time element our mulling time is about 3 min. We would prefer 5 min. if possible.

Plant No. 3—Much more attention even than we are now giving it will pay big dividends in reduction of scrap. At present, the shortage of proper type of laborers and semi-clerical subforeman type of supervision is a great handicap to better control and speedier progress.

Plant No. 4—No comment.

Plant No. 5—All our system sand is equivalent of facing sand.

Plant No. 6—Know of nothing special about our sand control work.

Plant No. 7—Study of behavior of sand mixtures used in respect to high temperature effects.

Plant No. 8—No comment.

Plant No. 9—No comment.

Plant No. 10—No comment.

Plant No. 11—(1) Inspect and test all incoming raw materials. (2) Investigate new products. (3) Maintain records of sand tests and investigations for future references. (4) Correlate scrap and sand troubles to minimize amount of scrap.

Plant No. 12—Control of dry strength is very important for malleable products.

Plant No. 13—In the control of molding sand, we are constantly aiming for the following: (1) To prepare a sand that can be easily worked by the molders and reduce molding losses to a minimum; (2) a sand that will produce castings free from cuts, blow holes, scabs, roughness, dirt and other defects; (3) a sand that will clean easily from the castings; (4) a sand that can be prepared for nominal cost.

Plant No. 14—Covered under other questions.

Discussion

W. A. KENNEDY[1] *(written discussion):* The replies to the questionnaire on "Malleable Sand Control" serve to emphasize the complexity of a problem which is of vital importance in the operation of a modern foundry. Quite logically and rather definitely the indications are that it is economically impractical to consider any move leading to the standardization on one grade or type of sand, with the result that the various foundries start off with a wide range of variable factors which have direct bearing on the important questions of bond, permeability, and fusibility.

The replies indicate that the importance of adequate bond and permeability are generally recognized, and there is a gratifying indication that up-to-date testing devices and plant operating procedures are being employed for periodically checking both of these points. Only two of the foundries mention refractoriness or hot strength of the mixture as being subject to follow-up control. Possibly this matter was slighted in filling out the questionnaire and is being given more consideration than is indicated by the replies, but if not it may be something which can properly receive more general consideration. It seems probable that this is a point which will be discussed at some length in one or more of the papers which are now being prepared.

Question No. 4 brings up a problem which may warrant some study with the ultimate end in view of setting up some practical working standards. For instance, a set of photographs might be selected as representing a number of commercially acceptable finishes ranging from "fine" to "coarse," the coarse grade to be set at a limit which would be acceptable under conditions such as those which would hold for Plant No. 10 but still be in line with reasonably good practice from an industrial angle. If this were to be done, the Association would then be in position to issue a strip of half-tones showing at full size or at ordinary reading glass magnifications an acceptable definition of a range which

[1]Supervisor of Products, Grinnell Co., Providence, R. I.

could include divisions such as (1) "fine-special," (2) "fine," (3) "medium," (4) "coarse," (5) "coarse-maximum." Certainly it is hard to believe that the terms fine, medium, and coarse which appear in the replies are based on an adequately defined grading. Yet finish is an important requirement for many products.

The answers to Questions 7 to 12 show that the importance of sand control is uniformly recognized and that standard equipment is in general use. This affords a good background for the development of a comprehensive coverage of average working requirements and ability to reasonably define results which an organization may expect to obtain. The reply from Plant No. 3 is unusually complete. It presents the facts so clearly and concisely that it is probable some worth-while comparisons and useful information would be obtained if the other foundries were to be requested to fill out a follow-up questionnaire which would be based on No. 3's coverage. Doubtless all of the foundries are not in position to give as much detail, but probably such a questionnaire would produce additional facts which would be of assistance in classifying the practices as developed to date.

R. W. LINDSAY[2] *(written discussion):* The answers to the first three questions of the questionnaire give a good idea of the type of work being handled in malleable foundries both as to size and applications of the castings. Obviously the finish on these castings varies, but in most instances it tends to run to the medium or fine. The tendency seems to be for jobbing work to be turned out to a finer finish, but this depends to a large extent on the nature of the work. The natural extremes are the work produced by No. 10 such as housings and the like where finish would be a secondary factor as in comparison to the small castings of the type made by No. 1 in which finish would be more important.

Although the details apparently differ, the general principles on sand processing seem to be the same. The plants appear to be about evenly divided between the use of heaps and continuous sand handling systems. Facing sands are prepared by mulling shakeout sand with new sand, bond, sea coal and water. The ample use of sand testing and control equipment is noted to be common to all plants. A more or less representative layout includes: Moisture tester, permeability apparatus, strength machine (green and dry strength), specimen rammer, screen series and shaker (grain distribution and fineness).

Other tests mentioned in isolated instances were hot property tests employing a dilatometer and the determination of deformation and flowability characteristics.

Most of the plants attempt to set up some type of specification for buying their sand. There appears to be a good deal of divergence in this respect. Although each plant has its own reasons, no doubt, for their choice of specifications, that stated by Plant No. 10 appeared to be concise and to cover the purchasing of this important raw material rather thoroughly.

Again each plant must have its own ideas for the sand standards they are employing for their heaps or systems. However, the thoroughness of Plant No. 3 and Plant No. 11 might yield the best results in the long run. It would seem that adherence to such standards plus the keeping of close records against casting yield or quality would pay good dividends. The value of close checking of the standards they have set up appears to be recognized by all plants answering the questionnaire. This is emphasized by most answers to Question 11. The answer from Plant No. 10 to this question appears to sum up the essential fundamentals of sand control work in good general fashion thus:

Control of strength for control of hot tears.

Collapsibility of cores for control of cracks and hot tears.

Permeability for elimination of blows.

Moisture control for eliminating dirt and blows.

Some of the answers given to the final question (No. 12) regarding sand control work were especially pertinent. A consideration and combination of the answers from Plants No. 3, 11 and 13 would probably form as good a summary as any for the aim of all foundries in their sand control.

R. J. ANDERSON[3] *(written discussion):* We find that the summary on "Malleable Foundry Sand Control" contains valuable information as to what other malleable foundries are doing along the line of sand control. Particularly noticeable is the importance that is being attached to sand control by other foundrymen.

We consider sand control to be a vital factor in the production of good castings in our plant. In the past year two continuous sand handling systems have been installed, and this has been a great aid in achieving closer sand control. This installation also brought to light the need for closer supervision on sand.

We believe that we have a fair arrangement for sand control in our malleable foundry, and expect to improve this considerably by the establishment of a sand control and experimental laboratory, which is included in our present building program.

[2]Assistant Professor of Metallurgy, Pennsylvania State College, State College, Pa.

[3]Works Manager, Belle City Malleable Iron Co., Racine, Wis.

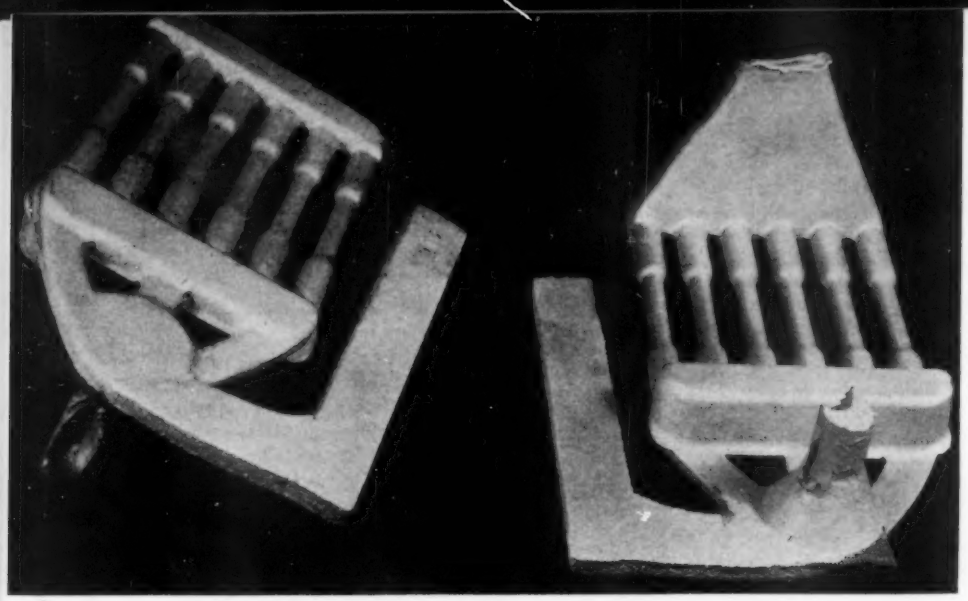


Fig. 1—Rectangular panel attached to the six-bar test casting.

Effect of Gas on the Properties of MAGNESIUM *Sand Casting Alloys*

By R. S. Busk and R. F. Marande,
Metallurgical Dept., The Dow Chemical Co., Midland, Mich.,
and W. C. Newhams, Metallurgical Dept., Bay City, Mich. Div.

THE problem of gas in magnesium has not been generally recognized since the pinhole type of porosity found in other metals rarely occurs. The possible existence and the effects of microshrinkage in magnesium castings have been known for some time. Investigation has shown that gas will produce an appearance substantially the same as microshrinkage.

During numerous experiments the observation was made that the severity of microporosity is proportional to exposure to moisture. Also, dry hydrogen gas bubbled through a molten magnesium alloy will produce all stages of porosity from a gradual increase in microporosity to hot tears and bubbles.

Many Tests Made

Many tests have been made to find suitable methods of removing the effects of gases, and particularly hydrogen, in metals. In general, two methods have proved to be successful[1,2,3]; (1) lowering the partial pressure as by standing or bubbling a gas insoluble in the metal, and (2) introducing an agent that reacts with the hydrogen in such a way as to remove it. An effective method of removing hydrogen by lowering the partial pressure only is by bubbling an inert gas, e.g., helium, through the molten metal. However, chlorine is more effective because it not only reduces the partial pressure but also combines with the hydrogen.

Work on Two Alloys

All of the work reported in this paper is confined to two alloys, compositions of which are given in Table 1.

It was necessary to develop a numerical system of measuring the degree of porosity characteristic of a given melt. A series of shapes was tried, including a wedge, a cone and several types of rectangular and triangular panels. One rectangular and one triangular panel were finally selected, as shown in Figs. 1, 2, 3 and 4. The rectangular panel is so designed that there always will be porosity in the end farthest from the gate, with the commercial alloys studied. As the porosity tendency of the alloy increases for any reason, the porosity will progress toward the gate until it permeates the whole panel. Thus the amount of space left free of porosity is a measure of the soundness of the alloy. This panel is suitable for studying low porosity alloys, such as "C" alloy.

Triangular Panel Porosity Free

The triangular panel was developed specifically for "H" alloy and normally is porosity free. As gas is introduced or picked up, porosity will begin to appear at the gate or base end of the triangle and progress toward the apex. Thus the length of porosity-free space in inches from the apex toward the gate end is a measure of the soundness of the melt. The appearance and rating system of porosity in the triangular panel is illustrated in Figs. 5 to 10 inclusive.

The effect of pouring temperature and the consistency of the results with the triangular panel are illustrated in Table 2. The figures shown represent an average of the ratings obtained on four panels poured at each temperature. The ratings were consistent to plus or minus ½ in. at each temperature. From 1300 to 1600° F. the average ratings agreed to within plus or minus one inch. All panels discussed in this paper were poured at 1400° F., and a difference of one inch is considered significant.

Test bars usually are sound, but if appreciable gas is present porosity may appear. At such times the test

Table 1

COMPOSITIONS AND HEAT TREATMENTS OF ALLOYS

Alloy	Composition, per cent Al	Zn	Mn	Mg	Heat Treatment	Typical Heat Treated Tensile Properties: Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
C	8.3-9.7	1.7-2.3	0.10	Rem.	2 hr. from 500° F. to 770° F. + 16 hr. at 770° F.	10	16,000	40,000
H	5.3-6.7	2.5-3.5	0.15	Rem.	2 hr. from 500° F. to 730° F. + 10 hr. at 730° F.	12	14,000	40,000

bar itself may be used as a measure of the amount of gas present. As shown in Fig. 1, a 6-bar test bar pattern was used instead of the conventional 4-bar type. The former was chosen because this 6-bar pattern is more sensitive to porosity than the latter.

Experimental Data

The apparatus used for introducing the various gases is shown in Fig. 11. This assembly was developed specifically for introducing chlorine and consists of the gas cylinder and pressure gauge, a rubber tube, an iron tube and, finally, a graphite tube leading into the metal. A plain steel pipe would have sufficed for all gases except chlorine, but, to avoid changing, this apparatus was used throughout. Tensile properties were determined on ½-in. diameter bars without machining. All bars were tested in the solution heat treated state (Table 1). The yield strength is defined as the stress at which there is 0.2 per cent deviation from the modulus line. The elongation is given in per cent in 2 in.

Metallographic examination[4] was made by cutting samples at the fracture from the bars having the highest and the lowest tensile strength in each set of six. The average grain diameter is expressed in inches. The degree of solution obtained during heat treatment is indicated by the compound rating which is zero for complete solution and 10 for as-cast metal. Voids due to microporosity or heat treatment (burning) are rated on a scale which is similar to that used for compound.

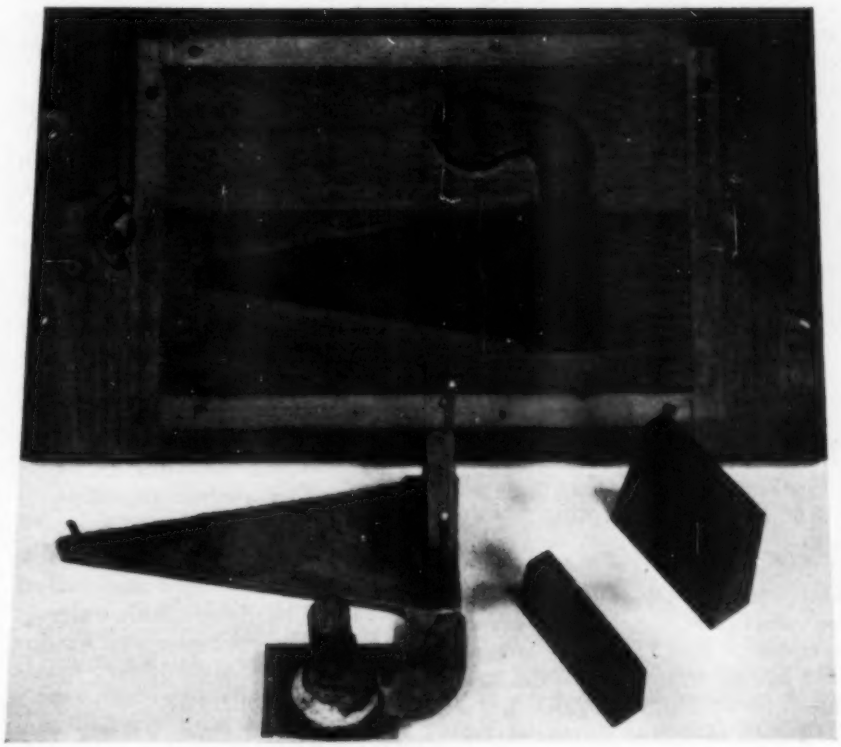


Fig. 2—Triangular panel.

Laboratory Tests

Preliminary experiments in which various gases were bubbled through molten magnesium alloys showed that only hydrogen and water vapor caused the extreme type of porosity, evidenced by gas bubbles in the risers. Winterhager[5] also has shown that hydrogen is the major gas constituent in solid magnesium. Therefore, first attention is given to this gas.

Hydrogen: Figure 5 illustrates the appearance of a panel that has been treated with chlorine until substantially free of gas, and Fig. 6 shows

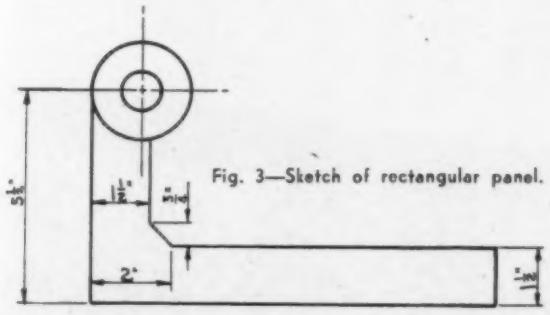
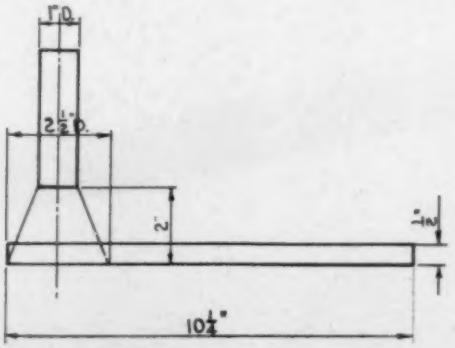


Fig. 3—Sketch of rectangular panel.



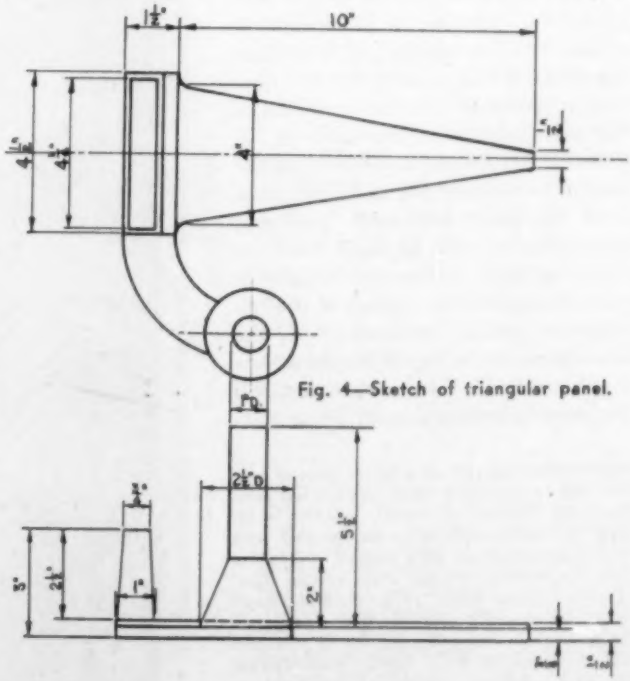


Fig. 4—Sketch of triangular panel.

Table 2
EFFECT OF POURING TEMPERATURE ON POROSITY SHOWN BY TRIANGLE PANEL
(Ingot H Alloy Superheated 15 Min. at 1700° F.)

Pouring Temperature, °F.	*Soundness, Inches*
1200	2¼
1300	6
1350	7¾
1400	7⅜
1450	7⅞
1500	6
1600	6¾

a panel poured from the same melt after gassing with hydrogen for 15 min. at 1550° F. The effect of standing at 1400° F. after being treated with hydrogen is shown in Figs. 7 through 10. The porosity gradually disappears until after 2 hr. the panels are practically as clear as before treatment. This effect of standing after hydrogen treatment is similarly shown for "C" alloy in Table 3.

In each of the remaining experiments on the effects of various gases, 300 lb. of "H" alloy is treated with chlorine for ½ hr. to reduce the gas content to a low and equivalent basis for all tests. The gas being studied was then added, and at periodic intervals about 10 lb. of metal was ladled out to pour panels and test bars. All gases except those deliberately saturated with water vapor were dried by passing them over $CaCl_2$.

Dry Hydrogen Tested

The effect of dry hydrogen followed by chlorine is illustrated in Table 4. The amount of hydrogen used was not measured, but the flow was adjusted so that the agitation of the melt was about the same as for chlorine. It should be noted that the tensile properties are markedly lowered by treatment with hydrogen and subsequently brought back to their original values by treatment with chlorine. The ratings of the triangular panels indicate that the soundness of the metal can be as low as about 4 in. of free space and still produce sound test bars. Thus casting design influences the presence of porosity due to gas as well as that due solely to shrinkage.

The ability of helium to remove hydrogen is illustrated in Table 5. The flow of helium was adjusted in the same manner as that of hydrogen. In 30 min. the helium treatment did not raise the triangular panel rating to 10 nor the properties to their original values. However, if continued for a sufficient length of time, helium will remove all of the gas porosity. This is illustrated by a run which was made on remelted scrap. The soundness of the metal as melted was 3. After a 15-min. treatment with helium the rating increased to 10.

Water Vapor: The effect of water vapor on gas porosity was studied by saturating helium with water at 165° F. The apparatus used for this test consists of a gas meter, a constant temperature water bath, and a hot tube to prevent condensation. The helium was bubbled through two bottles of water in succession, which were maintained at a temperature of 165° F. in the water bath.

The results obtained are tabulated in Table 6. After one cu. ft. of gas had passed through the metal, the soundness was reduced from 10 to 8½. It then went progressively down to a value of 3 after 15 cu. ft. of gas had been bubbled through the melt. Subsequent treatment with 15 cu. ft. of dry helium failed to bring the soundness rating back to its original value.

Mechanical Properties Normal

The mechanical properties remain about normal during the original treatment of the melt with dry helium for 30 min. at 1500° F. (Table 6). The properties decreased as the water vapor was introduced. The properties did not return to their original values upon subsequent treatment with dry helium at 1400° F., principally due to an increase in grain size. This effect is to be expected when a melt is held at a low temperature for this length of time after superheating.

Natural Gas: There sometimes is danger of hydrocarbons coming into

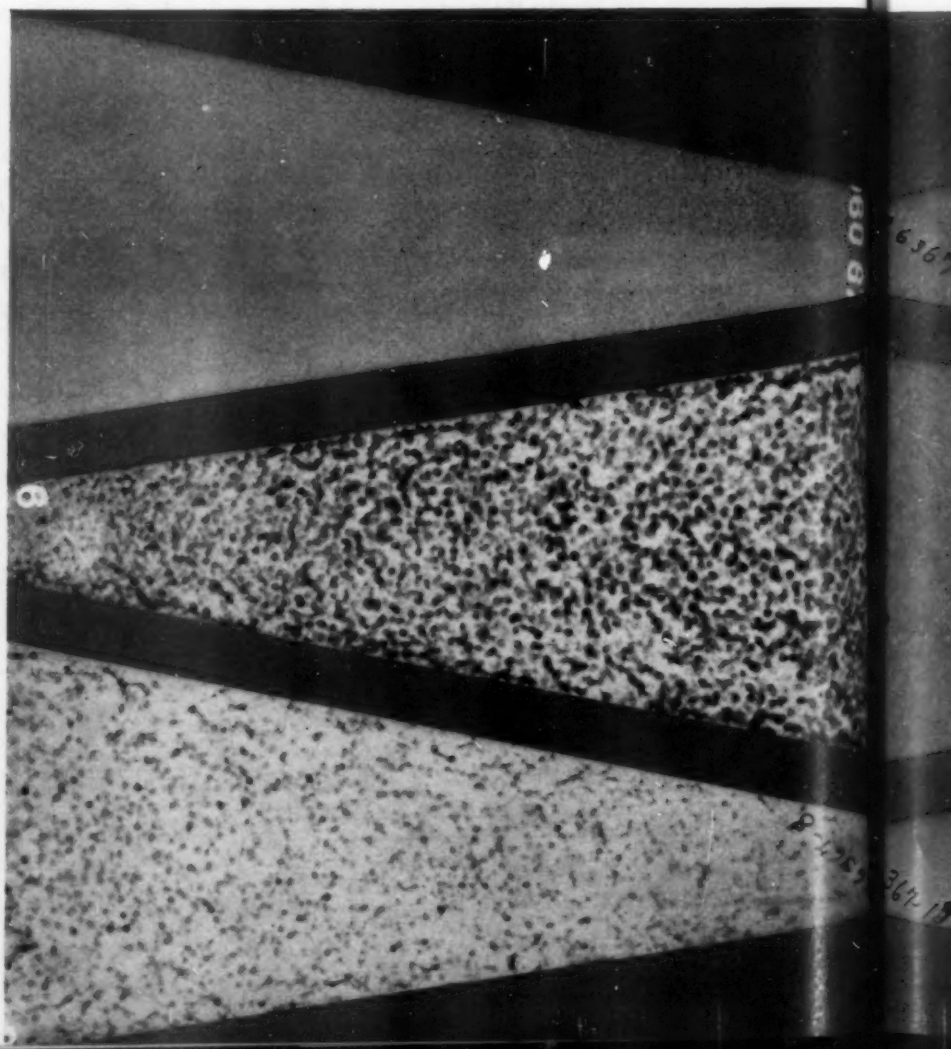


Fig. 5—Radiograph of a panel poured with gas-free magnesium alloy chlorinated with 0.02 lb. Cl_2/lb. of metal. Rating = 10. Fig. 6—Radiograph of panel poured with gas-free magnesium alloy treated with hydrogen for 15 min. Porous areas appear dark. Rating = blow holes. Fig. 7—Radiograph of panel poured with gas-free magnesium alloy treated with hydrogen for 15 min. and let stand for 15 min. Porous areas appear dark. Rating = blows and hot tears.

contact with molten magnesium. The ability of magnesium to crack these compounds and the possibility of subsequent gassing is of interest. There also have been some suggestions that natural gas can be used to refine the grain. Therefore, the effect of natural gas on porosity was investigated. The data in Table 7 show that natural gas used in this way can result in porosity and a resultant loss in tensile strength. Subsequent treatment with chlorine removed the effects of the natural gas after about 10 min.

Effect of Sulphur Dioxide

Sulphur Dioxide: Because SO_2 commonly is used with molten magnesium, knowledge regarding its effect on porosity is important. The data obtained on the effect of SO_2 on porosity are shown in Table 8. If SO_2 has any effect it is not discernible by the rather sensitive triangular panel after 30 min. treatment. No effect was detected by any of the other measurements shown in the table.

Carbon Dioxide: Table 9 shows that carbon dioxide has a slight effect on increasing the porosity and decreasing the mechanical properties. Any detrimental effect is corrected after about 5 min. treatment with chlorine.

Oxygen: The effect of treating "H" alloy with oxygen is shown in Table 10. After 10 min. the metal became so slushy that the molds would not run. At the end of 30 min., test bars were obtained by pouring the metal directly down the sprue. This is in contrast to the usual magnesium foundry practice of pouring into a pouring cup. The increase in porosity shown in the triangular panel may be due to the slushiness and lack of feeding caused by the MgO present rather than from oxygen dissolved in the metal.

The period between the end of the oxygen treatment and the start of the chlorine treatment may have been sufficiently long to settle out some of the MgO and result in an increase in soundness.

Porosity Increased

Nitrogen: Treatment of molten "H" alloy with nitrogen increased the porosity in the triangular panel, as shown in Table 11. The test bar properties were not affected. Subsequent treatment with chlorine removed the effects of the nitrogen within 10 min.

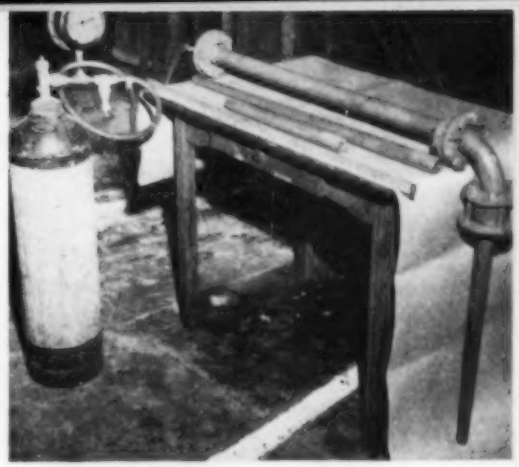


Fig. 11—Apparatus used to introduce gas into molten metal.

Commercial Foundry Tests

Since porosity is a problem in the magnesium foundry, it is desirable to determine to what extent this condition is due to gas. Therefore, a study to discover the sources, and means of prevention and elimination of gas was initiated.

Effect of Condition of Metal Charge on Porosity: A statistical study of test bars was made in the production foundry, relating metal condition to porosity. Table 12 describes the variations of metal treatment studied to determine the effect on gas porosity. The same 6-bar test mold previously described also is used in these experiments. In all except the last test in Table 12, the metal was melted, superheated and poured in a 150 lb. capacity crucible. In the last test the metal was premelted, transferred to the crucible, superheated and poured according to the usual practice[6].

Metal Dried

Metal to be dried was placed in the ordinary steel tote box (about 6 ft. x 3 ft.) and heated in a gas-fired oven in such a way that the contents of the box reached 212° F. in about ½ hr. Therefore, a one hour drying period indicates that

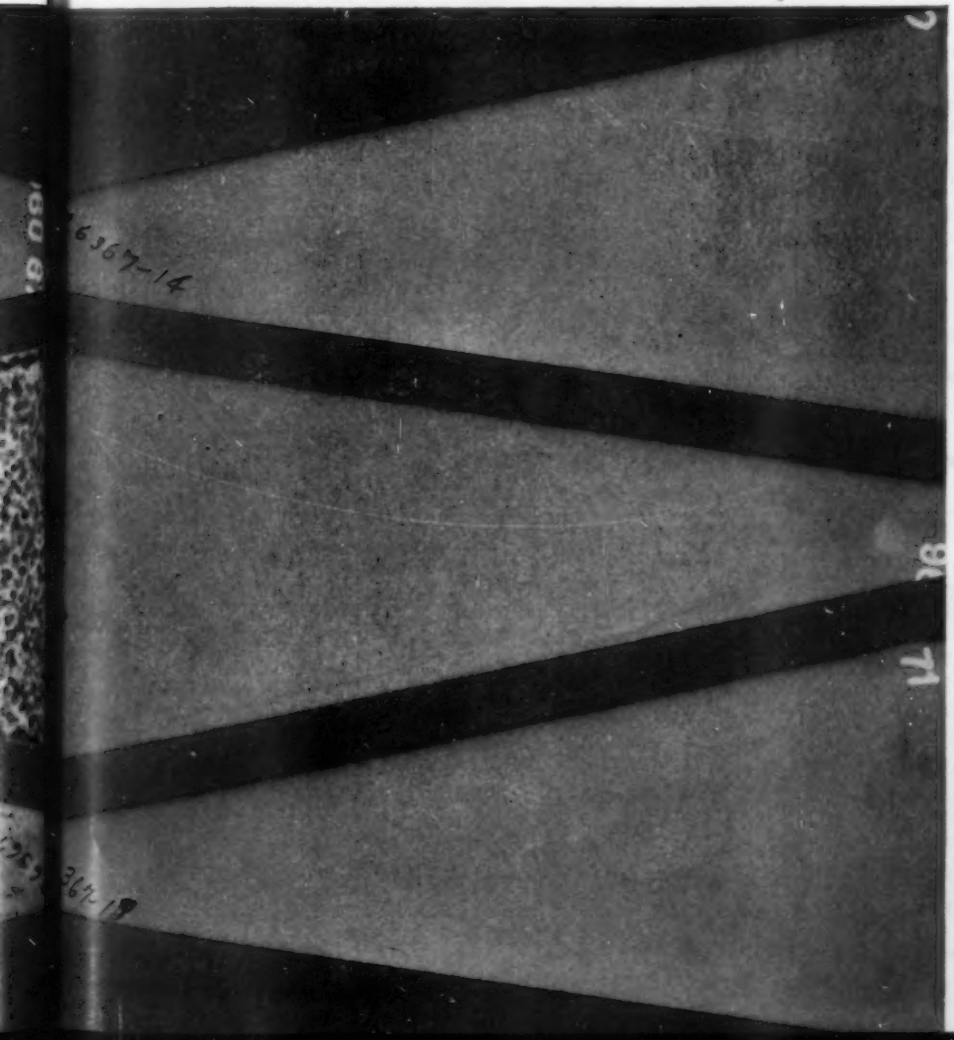


Fig. 8—Radiograph of panel poured with gas-free magnesium alloy treated with hydrogen for 15 min. and let stand for 30 min. Porous areas appear dark. Rating = 0.
Fig. 9—Radiograph of panel poured with gas-free magnesium alloy treated with hydrogen for 15 min. and let stand for 1 hr. Porous areas appear dark. Rating = 4½.
Fig. 10—Radiograph of panel with gas-free magnesium alloy treated with hydrogen for 15 min. and let stand for 2 hr. Porous areas appear dark. Rating = 6½.

Table 3
EFFECT OF STANDING ON H_2 TREATED "C" ALLOY

Time, minutes		Soundness, inches	Heat Treated Tensile Properties: Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
Treat H_2	15	Blow Holes	0.9	12,900	15,300
Let stand at 1400° F.	15	Hot Tears	0.7	14,400	16,800
	30	Hot Tears	1.4	16,700	25,700
	120	0	3.0	19,400	34,600
	60	2	4.6	18,800	37,900
	180	4	5.3*	19,800*	40,000

*The relatively low elongation and high yield strength are due to slow cooling after heat treatment, resulting in partial precipitation hardening.

the metal was above 212° F. for at least ½ hr. In Table 12, an entry under "porous" indicates at least one porous test bar from a given mold, while an entry under "sound" means all bars from a given mold were radiographically sound. Since the work on the triangular panel shows that considerable porosity must be evident in the panel before the test bar will be porous, this is in effect a measure of the presence of gas.

The most significant part of this table is the fact that ingot metal melted and cast into test bars produced radiographically sound bars, while riser scrap not dried produced 100 per cent porous bars. It should be noted that the special 6-bar pattern was used, and that this work was done in the summer. Drying the scrap reduced, and premelting markedly reduced the number of porous test bars obtained. Drying at 212° F. will not dissociate $Mg(OH)_2$, but it will be decomposed at melting temperatures with liberation of hydrogen. This may explain the failure to completely eliminate the porous test bars by drying at 212° F.

Effect of Cl_2 on Quality of Commercial Castings: Since the previous section indicates that porosity may be a problem even though scrap is dried or premelted, the effect of removing the gas by chlorinating the metal just before pouring was investigated.

Table 13 shows the effect of chlorination on several types of commercial castings. Open pot melting refers to the operation of melting metal in a large pot and ladling it into the molds. In crucible melting the metal is poured directly from the crucible into the mold[6].

The chlorine used was weighed and tabulated as lb. of Cl_2 per lb. of metal treated. In order to insure adequate degassing, about 0.02 lb.

Table 4
EFFECT OF H_2 ON "H" ALLOY*

Treatment: Time, min.	Gas	Weight of Gas, lb./lb. metal	Soundness: Triangle Panel, inches	Test Bars	Metallography: Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Heat Treated Tensile Properties: Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	H_2		10	Sound	<1	2	4½	13.3	13,500	40,300
2	H_2		10	Sound	<1	2	5	12.5	14,000	40,800
5	H_2		8½	Sound	<1	2	4½	14.2	13,700	44,200
10	H_2		3½	Sound	0	3	4	13.2	13,500	40,000
20	H_2		0	Porous	0	5	3½	6.5	13,300	30,800
30	H_2		Hot Tears	Hot Tears	0	4½	4	3.8	12,500	24,000
0	Cl_2	0	¼	Porous	<1	3½	4½	5.4	13,100	27,900
2	Cl_2	0.0016	0	Porous	0	3½	4	6.8	13,000	30,500
5	Cl_2	0.004	1	Porous	<1	3	4½	7.7	13,600	34,500
10	Cl_2	0.009	4¼	Sound	<1	2	4	15.3	14,000	41,800
20	Cl_2	0.0185	10	Sound	<1	1	4	16.3	13,700	41,700
30	Cl_2	0.029	10	Sound	<1	1	3	15.7	14,300	41,900

*Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., gassed at 1500° F., then treated with Cl_2 at 1400° F.

Table 5
EFFECT OF He ON H_2 SATURATED "H" ALLOY*

Treatment: Time, Min.	Gas	Soundness: Triangle Panel, inches	Test Bars	Metallography: Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Heat Treated Tensile Properties: Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	H_2	10	Sound	2	2½	5	14.1	13,400	41,100
2	H_2	10	Sound	1½	3	4	13.6	14,300	41,400
5	H_2	5¾	Sound	1½	3	3½	10.2	14,700	36,800
10	H_2	0	Porous	1	3½	3½	6.5	14,200	31,100
20	H_2	Hot Tears	Porous	2	3½	4½	3.1	13,100	21,700
30	H_2	Bubbles	Porous	2	4	5	1.8	11,500	17,600
0	He	Hot Tears	Porous	2	4	6	3.2	11,700	21,000
2	He	Hot Tears	Porous	2	4	5	4.5	12,100	24,800
5	He	0	Porous	2	4	5	5.2	12,900	27,400
10	He	0	Porous	2	3½	5	5.1	13,000	27,900
20	He	3	Porous	2	3½	6	9.0	12,900	34,800
30	He	5¼	Sound	2	3½	7½	11.0	12,900	37,300

*Treated with 0.02 lb. Cl_2/lb. metal, superheated 15 min. at 1700° F., gassed with H_2 at 1500° F., treated with He at 1400° F.

Table 6
Effect of H_2O on "H" Alloy*

Treatment			Soundness		Metallography			Heat Treated Tensile Properties		
Time, Min.	Cu. Ft. Gas	Temp., °F.	Triangle, inches	Test Bars	Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	Dry He	1500	10	Sound	<1	1	4	14.0	13,600	40,800
2	Dry He	1500	10	Sound	<1	3½	4½	11.5	13,600	38,800
5	Dry He	1500	10	Sound	<1	2½	4	12.7	13,700	39,600
10	Dry He	1500	10	Sound	<1	2	3	11.6	14,500	39,700
20	Dry He	1500	10	Sound	<1	2½	4	12.9	14,500	40,800
30 18	Dry He	1500	10	Sound	<1	4	4	11.7	14,200	39,700
0	He + H_2O	1500	10	Sound	<1	4	4½	11.3	13,300	38,200
1	He + H_2O	1500	8½	Sound	<1	4	4	11.7	13,500	38,500
2	He + H_2O	1500	8	Sound	<1	3	4	11.8	13,500	38,300
5	He + H_2O	1500	6	Sound	0	2½	5	10.4	12,300	35,300
10	He + H_2O	1500	4	Sound	0	3½	4	9.5	13,300	36,000
75 15	He + H_2O	1500	3	Porous	0	4	4	9.6	13,500	36,800
0	Dry He	1400	4	Porous	<1	4	5½	9.5	12,300	34,700
2	Dry He	1400	4	Sound	<1	4	5	9.8	12,500	35,800
5	Dry He	1400	4¼	Sound	<1	4	5	9.6	12,300	35,200
10	Dry He	1400	6¼	Sound	<1	4½	5½	9.3	12,500	35,000
20	Dry He	1400	6¼	Sound	<1	4½	6½	10.0	12,100	35,700
30 15	Dry He	1400	8¼	Sound	<1	2½	9	9.0	11,500	34,000

*Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., then treated with 18 cu. ft. of dried He, then with 15 cu. ft. of He saturated with H_2O at 165° F., then with 15 cu. ft. of dried He. Poured at 1400° F.

Table 7
Effect of Natural Gas* on "H" Alloy†

Treatment		Soundness		Heat Treated Tensile Properties		
Time, Min.	Gas	Temp., °F.	Triangle, inches	Test Bars	Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	Natural Gas	1500	10	Sound	13.2	14,400	40,800
2	Natural Gas	1500	10	Sound	12.9	14,800	40,400
5	Natural Gas	1500	10	Sound	9.5	14,100	36,400
10	Natural Gas	1500	10	Sound	10.2	14,200	37,400
20	Natural Gas	1500	5	Sound	7.1	14,300	33,800
30	Natural Gas	1500	3¾	Porous	7.9	13,300	33,200
0	Cl_2	1400	4¼	Sound	10.8	14,100	37,900
2	Cl_2	1400	4¾	Sound	8.8	13,800	34,900
5	Cl_2	1400	5½	Sound	9.8	14,400	37,300
10	Cl_2	1400	10	Sound	11.2	13,800	38,200
20	Cl_2	1400	10	Sound	12.4	13,800	39,700
30	Cl_2	1400	10	Sound	14.3	14,200	41,200

*Typical Gas Analysis, per cent: CH_4—77.85; C_2H_6—8.59; N_2—9.31; O_2—0.09; Propane—3.00; Butane—0.77; Pentane—0.26; Hexane—0.13. The gas was dried by passing over $Mg(ClO_4)_2$.
†Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., gassed with natural gas at 1500° F., then treated with Cl_2 at 1400° F.

of chlorine per lb. of metal should be used (Table 4). The effectiveness of the chlorination was measured by radiographing the castings and estimating the tensile strength by the amount of porosity present in the *most porous section*[7]. This method is accurate to within 2000 psi. An estimate of 34,000 psi. indicates no porosity visible in the radiograph.

The improvement after chlorination is evident in all but two cases. In the instances where chlorination did not remove all the porosity, and sufficient Cl_2 was bubbled through (0.02 lb. per lb. of metal), the remainder can be attributed to shrinkage and lack of feeding.

Table 8
Effect of SO_2 on "H" Alloy*

Treatment			Soundness		Metallography			Heat Treated Tensile Properties		
Time, min.	Gas	Wt. of Gas, lb.	Triangle Panel, inches	Test Bars	Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Elongation, per cent in 2 in	Yield Strength, psi.	Tensile Strength, psi.
0	SO_2	0	10	Sound	<1	1	4	13.8	14,100	41,200
2	SO_2	0.22	10	Sound	<1	2	4	13.1	13,700	40,700
5	SO_2	0.54	10	Sound	<1	1½	4.5	14.2	14,500	41,300
10	SO_2	1.1	10	Sound	<1	1	3	15.4	14,900	42,400
20	SO_2	2.2	10	Sound	<1	1	3.5	11.8	14,900	40,200
30	SO_2	3.25	10	Sound	1	1	4	12.2	14,200	39,500
0	Cl_2	0	10	Sound	1	1	4	16.5	14,300	42,500
2	Cl_2	0.38	10	Sound	<1	1	4	16.2	14,000	41,500
5	Cl_2	0.96	10	Sound	1	1	4	15.6	14,300	42,200
10	Cl_2	1.9	10	Sound	1	<1	4	14.6	14,200	42,100
20	Cl_2	3.8	10	Sound	<1	1	4	13.3	13,800	41,000
30	Cl_2	5.75	10	Sound	1	1	4	13.7	14,300	41,300

*Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., gassed at 1500° F., then treated with Cl_2 at 1400° F. 300-lb. melt.

Table 9

EFFECT OF CO_2 ON "H" ALLOY*

Treatment			Soundness		Metallography			Heat Treated Tensile Properties		
Time, min.	Gas	Wt. of Gas, lb.	Triangle Panel, inches	Test Bars	Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	CO_2	0	10	Sound	3½	2	5	12.7	14,200	41,000
2	CO_2	0.17	10	Sound	2½	1	5	12.8	14,500	40,400
5	CO_2	0.42	10	Sound	2	1	5	11.8	15,000	40,100
10	CO_2	0.84	10	Sound	2	2	5	12.1	14,500	41,300
16	CO_2	1.3	10	Sound	2½	1½	5	11.3	14,100	39,800
30	CO_2	2.5	7½	Sound	2	2	4½	11.2	14,200	39,300
0	Cl_2	0	7	Sound	2	2	4½	14.4	14,300	41,600
2	Cl_2	0.38	10	Sound	2	2½	4½	.....	.....	.....
5	Cl_2	0.96	10	Sound	1½	1	4	15.0	14,500	41,100
10	Cl_2	1.9	10	Sound	1	1	6	14.7	14,200	41,400
20	Cl_2	3.8	....	Sound	2	2	6	10.3	14,400	38,600
30	Cl_2	5.75	10	Sound	1½	1	5	14.4	14,200	40,600

*Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., gassed at 1500° F., then treated with Cl_2 at 1400° F. 300-lb. melt

Table 10

EFFECT OF O_2 ON "H" ALLOY†

Treatment			Soundness		Metallography			Heat Treated Tensile Properties		
Time, min.	Gas	Wt. of Gas, lb.	Triangle Panel, inches	Test Bars	Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	O_2	0.0	10	Sound	2½	1	4	13.0	13,800	39,700
2	O_2	0.22	10	Sound	1	1	4½	12.6	14,100	40,100
5	O_2	0.54	10	4 bars porous	1	2	4½	7.2	14,200	34,000
10	O_2	1.1	8¼	Sound	....*	....	....	.....	.....	.....
20	O_2	2.2	9¼	Sound	....	....	....	.....	.....	.....
30	O_2	3.25	6¼	2 bars porous	1	1	4	11.9	14,500	40,200
0	Cl_2	0	10	Sound	½	½	3½	14.8	14,500	42,300
2	Cl_2	0.38	8¾	Sound	1	1	4	13.7	14,100	41,100
5	Cl_2	0.96	10	Sound	1	1	4	16.3	13,800	42,300
10	Cl_2	1.9	10	Sound	½	1	4	14.8	14,100	41,300
20	Cl_2	3.8	10	Sound	3	½	7	13.3	13,800	39,800
30	Cl_2	5.75	10	Sound	1	1	4½	14.8	13,800	41,200

†Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., gassed at 1500° F., then treated with Cl_2 at 1400° F. 300-lb. melt.
*The addition of O_2 made it difficult to fill the mold. After 10 minutes and 20 minutes the test bar mold did not fill at all. After 30 minutes the mold was filled by pouring directly down the sprue.

Table 11

EFFECT OF N_2 ON "H" ALLOY*

Treatment			Soundness		Metallography			Heat Treated Tensile Properties		
Time, min.	Gas	Wt. of Gas, lb.	Triangle Panel, inches	Test Bars	Compound	Porosity and Burning	Grain Size, in. x 10^{-3}	Elongation, per cent in 2 in.	Yield Strength, psi.	Tensile Strength, psi.
0	N_2		10	Sound	2½	2½	4	14.0	14,300	41,200
2	N_2		10	Sound	2	2	4	14.8	14,000	41,200
5	N_2		10	Sound	2½	2½	4½	13.4	14,200	41,300
10	N_2		10	Sound	2½	2	4½	14.4	13,800	40,900
20	N_2		7½	Sound	2½	3	4	14.3	14,300	41,200
30	N_2		4½	Sound	2	3	4	14.8	14,100	41,600
0	Cl_2	0	6½	Sound	2	3	4	15.9	13,800	41,900
2	Cl_2	0.40	10	Sound	2½	3	4	15.5	14,000	41,600
5	Cl_2	1.00	7¼	Sound	2	3	4	15.6	14,400	42,200
10	Cl_2	2.00	10	Sound	2	2	3½	15.8	13,800	41,300
20	Cl_2	4.00	10	Sound	2	2	4	14.3	13,600	40,500
30	Cl_2	6.00	10	Sound	2	2	3½	15.1	14,000	41,400

*Treated with 0.02 lb. Cl_2/lb. metal at 1400° F., superheated 15 min. at 1700° F., gassed at 1500° F., then treated with Cl_2 at 1400° F. 300-lb. melt.

Chlorination in Premelting Pots: The previous section showed considerable benefit to be gained by chlorination in the pouring crucibles. Since magnesium alloys usually are melted in large premelting pots[6], it would be more economical if the chlorination could be carried out at this stage of the melting operation. Therefore, the effect of subsequent transfer of the metal to pouring crucibles was investigated (Table 14).

There was little significant change in the porosity rating of the panels when non-chlorinated metal was transferred from the premelting pots to the pouring crucibles. If anything, the soundness of the metal in the crucible was better than in the premelting pots, but the rating was still quite low. The slightly higher rating after transfer may be partially due to the better pouring conditions from the crucible than from the ladle used to dip from the premelting pot. When the metal was chlorinated in the premelting pots there was a definite improvement over non-chlorinated metal. Some of this benefit was lost in subsequent handling of the metal, but the soundness rating was better than when the metal was not chlorinated.

Fluxing Methods Investigated

To determine the reason for the increase in porosity after transferring chlorinated metal, the effect of fluxing methods was investigated. Two extreme cases were used: in one a scoop of flux was placed in the bottom of the crucible before filling, and in the other no flux was used except a very small amount sprinkled on the metal to keep down burning while filling the crucible.

When the metal was not chlorinated, there seemed to be a slightly better soundness rating when no flux was mixed in with the metal while filling the crucible.

When the metal was chlorinated in the premelting pots, and the flux was mixed in while filling the crucible, the results were very much the same as with the commercial practice. However, when flux was not mixed in while filling the crucible, the porosity rating approached more closely the value obtained when panels were poured directly from chlorinated metal in the premelting pot. Despite the use of the best fluxing practice, there always was more porosity after chlorinated metal was transferred from the premelting pots to the pouring crucibles.

Table 12

Effect of Metal Source on Porosity, "H" Alloy

Source	Porous** No.	Porous** Per Cent	Sound** No.	Sound** Per Cent
Riser Scrap, not dried	34	100	0	0
Riser Scrap, dried 1 hr.	44	60	29	40
Scrap, dried 2 hr.	11	55	9	45
Ingot, not dried	0	0	13	100
Ingot, dried 1 hr.	2	5	38	95
Premelt*	15	20	59	80

*Scrap, melted in a 1500 lb. premelting pot, then transferred to a crucible, superheated, and poured.
**If a mold of test bars contained at least one test bar which was porous by radiographic inspection, the mold was listed as porous.

Influence of Flux on Gas Porosity: Since the flux seemed to have an adverse influence on the gas porosity in transferring the metal from the premelting pots to the pouring crucibles, the effect of possible moisture in the flux was investigated.

The flux as supplied by the manufacturer is substantially free of moisture. However, some of the ingredients are hygroscopic and, therefore, protection of the flux during use is important. To illustrate this a drum of flux was left uncovered in the foundry for a period of time. Regular batches of ingot "H" alloy were melted in crucibles at intervals and triangular panels were poured. After only 3 days exposure the soundness rating decreased from 8½ to 6½ in.

When 4 lb. of flux, which was deliberately mixed with 3 per cent of water, was added to 100 lb. of "H" alloy, the soundness decreased from a rating of 7 in. to 4 in. free space. Therefore, drums of flux in the melting areas should be carefully covered except during immediate use in order to prevent moisture pick-up.

Discussion

The presence of gas in magnesium alloys can lead to a condition indistinguishable in the radiograph from microshrinkage. Photomicrographs of gas porosity and microshrinkage are shown in Fig. 12. The appearance of each is the same. The fact that microshrinkage can exist in the absence of any gas is indicated by the presence of considerable porosity in the rectangular panel even after full chlorination has completely removed all porosity in the triangle panel.

Table 13

Effect of Cl_2 on Quality of Commercial Castings

Cstg. No.	Run No.	Alloy	Cl_2, lb. per lb. metal	Wt. of Melt, lb.	Method of Melting	Radiographic Estimation* of Tensile Strength, psi.
1	1	C	0	300	Open Pot	19,800
			0.0064	300	Open Pot	29,500
1	2	C	0	300	Open Pot	21,200
			0.011	300	Open Pot	25,900
1	2	C	0	300	Open Pot	22,900
			0.031	300	Open Pot	27,300
1	4	C	0	300	Open Pot	20,900
			0.023	300	Open Pot	34,000
1	5	C	0	300	Open Pot	19,700
			0.02	300	Open Pot	30,200
2	6	C	0	350	Crucible	29,700
			0.02	350	Crucible	30,400
3	7	H	0	500	Crucible	23,200
	8	H	0.02	500	Crucible	31,500
4	9	H	0	500	Crucible	27,600
	10	H	0.02	500	Crucible	30,300
5	11	H	0	500	Crucible	23,200
	12	H	0.02	500	Crucible	32,900
6	13	H	0	500	Crucible	27,100
	14	H	0.02	500	Crucible	27,500

*Estimated at the most porous place in each casting. Since the porous areas examined may be much smaller in area than the casting section in which they are found, these estimated strengths are lower than the true strength of the whole section. These particular castings were chosen because they represented unusual porosity problems.

Table 14

EFFECT OF Cl_2 IN PREMELTING POTS FOLLOWED BY TRANSFER TO POURING CRUCIBLES, "H" ALLOY

Panel Poured from	*Conditions of Pouring*	*Cl_2*	*Soundness Inches Triangle Panel*	*No. of Panels*
**Premelting Pot	Commercial	No	3.1	80
Crucible	Commercial	No	4.0	115
Premelting Pot	Commercial	Yes	7.8	103
Crucible	Commercial	Yes	5.7	102
Crucible	*Flux Stirred in by Pouring	No	3.5	5
	Flux not Stirred in	No	4.7	10
Crucible	Flux Stirred in	Yes	5.5	6
	Flux not Stirred in	Yes	6.6	20

*Flux was placed in bottom of crucible before pouring metal from the premelting pot so that the stream of metal churned the flux into the forming pool of metal.
**Tilting type pots holding about 1500 lb. of metal. Alloy is melted and held in these pots, transferred to pouring crucibles as needed.

It has been demonstrated that of all the gases commonly encountered in the foundry only hydrogen and nitrogen will cause gas porosity. Of these hydrogen is by far the more serious. Hydrogen has a temperature and pressure dependent solubility in magnesium. Winterhager[5] determined the solubility for one atmosphere pressure to be roughly 26 mls. of hydrogen in 100 gms. of molten magnesium, but only about 20 mls. in the solid state at the melting point. The data are scattered, but probably represent a minimum solubility of hydrogen.

Hydrogen

If enough hydrogen is present to exceed the solubility at a pressure of one atmosphere plus the metal head at the freezing temperature, the gas will be precipitated as spherical bubbles, as shown in Fig. 6.

As the metal freezes, the contraction will cause interdendritic voids. These normally are filled by liquid metal from the unfrozen parts of the casting and, finally, from the risers. The partial pressure of hydrogen in each newly formed void is zero and, therefore, any hydrogen in the metal will diffuse into it. The pressure of the liquid feed metal acting to fill the void will be opposed by the pressure of any gas present in the void. When the two pressures are equal the flow of liquid metal will cease. With no restrictions in the casting due to design the pressure of the liquid metal normally will be atmospheric plus its own head. Under these conditions, in order to prevent the metal from filling the void, the gas pressure must be at least equal to atmospheric pressure. Therefore, the amount of hydrogen in the metal must exceed the solubility at one atmosphere.

If the efficiency of feeding* is decreased in any way, the amount of gas necessary to prevent filling of the void with metal will decrease with the feeding pressure, since the pressure of hydrogen is directly related to the solubility. If the efficiency of feeding drops to zero, the voids will not be filled even in the complete absence of gas.

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Magnesium is fortunate in having a high solubility for hydrogen at the melting point. This means that, if the casting design is good, the problem of gas in magnesium castings is a minor one. When the solubility is low at the freezing point, as for example in aluminum, any small amount of gas present will exert atmospheric pressure. In this case, gas becomes a major problem even with the best casting design.

Helium

If helium is saturated with water vapor at 165° F. and atmospheric pressure plus metal head pressure assumed to be 84.3 cm. Hg, there will be 0.0251 lb. of water per cu. ft. of helium (Table 6). The volume of helium was measured and the concentration of the water was calculated at 84.3 cm. Hg and 68° F. If this water vapor were to completely react with the magnesium, 14.5 liters of hydrogen would be liberated for every cu. ft. of helium introduced.

From the data in Table 6 it is found that porosity first appeared when one cu. ft. of helium was introduced. This is equivalent to a maximum of 14.5 liters of hydrogen. At this time there were about 240 lb. of metal in the crucible. If we take Winterhager's figure[5] of 20 mls. of hydrogen per 100 gms. of metal as the solubility at one atmosphere, it would require 22 liters of hydrogen to saturate the 240 lb. of metal.

Water Vapor Reaction

Even assuming complete reaction with the water vapor, less than atmospheric pressure of hydrogen was needed to produce porosity in the panel. After 15 cu. ft. of helium or an equivalent of 216 liters of hydrogen had been introduced, there still was no bubble formation. This is evidence that the total reaction—decomposition of water vapor and subsequent solution of hydrogen—is only about 10 per cent complete. Thus a pressure corresponding to only 1 to 2 liters of hydrogen in 240 lb. of metal is sufficient to produce porosity in the triangular panel, indicating a very low feeding efficiency for this type of casting. On the other hand, the test bars did not become porous until 15 cu. ft. of helium had passed through the metal. On the basis of 10 per cent reaction efficiency, this is equivalent to 22 liters of hydrogen. Since this is close to the atmospheric solubility of hydrogen, it indicates that the feeding efficiency of the test bar mold is high.

Porosity Visible

In Table 4, porosity first became visible after bubbling dry molecular hydrogen for 5 min. If the rate of flow of hydrogen is assumed to be the same as for dry helium (Table 6), this flow is equivalent to about 70 liters. Since in the foregoing discussion it was shown that at most 14.5 liters of hydrogen from water vapor was sufficient to cause porosity in the triangular panel, the gassing of metal by water vapor is much more effective than by molecular hydrogen.

That the solubility of hydrogen in molten magnesium alloys is dependent on pressure is shown by the fact

*By efficiency of feeding is meant the ration of the pressure on the liquid at the void to what it would be if the liquid at the void had a continuous and frictionless path to the atmosphere.

that hydrogen can be removed by standing, bubbling helium or bubbling chlorine. In each of these cases the partial pressure of hydrogen is initially zero, both above the melt and in the bubbles of helium or chlorine. For this reason the hydrogen will diffuse out of the metal into the area of lower pressure.

It is interesting to note (Figs. 5 to 10 and Tables 3, 4, and 5) that it requires more than 2 hr. to remove hydrogen by standing, more than 30 min. with helium and only 20 min. with chlorine. This may be explained by the fact that both the helium and chlorine bubbles increase the surface through which the hydrogen can diffuse, and the chlorine may react with the hydrogen to maintain the partial pressure at zero.

Because a large proportion of the metal melted in the foundry is remelted scrap, any continuous source of hydrogen will soon cause the hydrogen content of the metal to build up to its saturation value.

In view of the foregoing, the possible sources of hydrogen in the foundry should be critically analyzed. These sources can be divided into four main groups: (1) Atmosphere; (2) metal charge; (3) flux; (4) tools.

Atmosphere

There is moisture in the air at all times, and in the hot, humid days of summer the problem may become serious. The moisture in the air may act directly on the surface of the molten metal or indirectly on the flux, scrap or ingot charge, and tools which come in contact with the melt. Combustion products contain an appreciable amount of water vapor and may contribute to the hydrogen pick-up of the metal. Under ordinary conditions the partial pressure of hydrogen over the melt does not become sufficient to allow solubility and, therefore, direct gassing through the surface of the molten metal by the moisture of the air is not appreciable.

Metal Charge

The scrap metal returned for remelting may be an important source of moisture. This may be due to several causes. If a water blast is used to knock out cores or if the scrap is allowed to stand outdoors, it may be actually wet. Corrosion products consisting of MgO and $Mg(OH)_2$ may accumulate on the surface of the metal even though it is not actually wet. Water vapor is liberated when $Mg(OH)_2$ is heated to the temperature of molten magnesium. Any contamination of a melt by oil also should be avoided.

If metal is reclaimed from sludge, it may contain sufficient flux to pick up moisture on humid days. Even the ingot metal may carry hydrogen into the molten metal if it becomes exposed in the ways mentioned for scrap metal.

The effects of moisture and atmosphere on the metal charge can be partially corrected by drying the metal for at least ½ hr. at a temperature above 212° F., if the metal is not too badly oxidized. Sand blasting is an effective way to remove corrosion products.

Flux

The fluxes used for the protection of magnesium alloys, while essentially anhydrous at the start, are all hygroscopic and will pick up moisture from the air if left exposed. The effect of moisture in the flux can be aggravated by improper use and handling.

The best precautions are to keep the flux drums tightly covered and to avoid an excess of flux where its use its of doubtful value, such as in

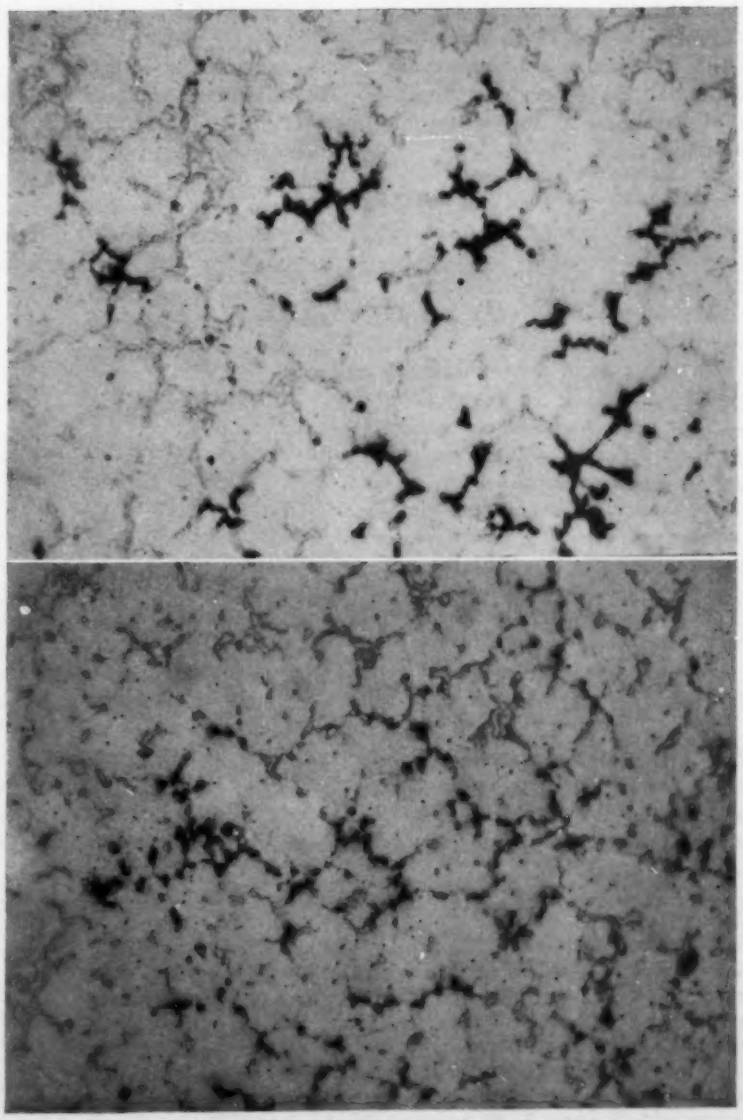

Fig. 12 — Top — Photomicrograph showing voids due to the presence of gas in as-cast magnesium alloy. 100x. Bottom — Photomicrograph showing microshrinkage in as-cast magnesium alloy. 100x.

the bottom of a crucible before pouring in the molten metal. Techniques recommended in the literature[6] will be satisfactory.

Tools

Stirrers, skimmers and ladles invariably become covered with flux which will pick up moisture from the air if left standing for any length of time. Such equipment should be thoroughly heated, to a red heat if possible, to eliminate moisture before placing in the metal.

It has been shown that there is a problem connected with the solubility of hydrogen in magnesium alloys, although it is not as serious as with some other metals. Because of the high solubility of hydrogen in solid magnesium at atmospheric pressure, the effects of gas porosity can be overcome by efficient feeding. Therefore, the problem of gas is secondary to the problem of casting design and proper gating and risering practice. With perfect feeding efficiency and normal foundry melting and superheating technique, the problem of gas porosity in magnesium alloys is substantially eliminated. However, in practice perfect feeding can not always be realized due to the engineering requirements of the castings produced. Therefore, gas porosity becomes increasingly important as the casting design becomes more difficult.

Problem Made Complex

The problem is made more complex due to the fact that all variations of feeding efficiency may exist in a given casting. Thus even complete removal of gas may leave certain areas still porous. Since feeding is not perfect in all sections of the ordinary casting, variations of gas content of the metal may cause variations in porosity during the production of a given casting.

The tendency of hydrogen to increase the porosity can be minimized by general foundry precautions leading to the exclusion of moisture from the molten metal. It is sometimes difficult to exclude all sources of moisture, and a general accumulation of hydrogen to the saturation point may result.

Since the solubility of hydrogen is pressure as well as temperature dependent, the removal of hydrogen from the molten metal can be effected by standing, bubbling with helium, or bubbling with chlorine. Of these, the most efficient is chlorine.

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Increased Use of GRAY CAST IRON In High Temperature Operations

By C. O. Burgess, Metallurgical Engineer, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y., and T. E. Barlow, Foundry Engineer, Battelle Memorial Institute, Columbus, Ohio

A SURVEY of the behavior of cast iron in elevated temperature applications has been made under authorization of the War Metallurgy Committee. Detailed information on 233 commercial applications of cast iron at temperatures over 450° F. was obtained from 99 concerns and 108 individuals. The resulting data show that within a temperature range of 450 to 1000° F., cast irons of controlled analysis can be successfully employed in numerous engineering applications. Included in these applications are castings which must resist pressure and be free from small dimensional changes.

Code Limitations

Codes limiting the use of cast iron to temperatures of 450° F. were established approximately 31 years ago, before modern cast irons of controlled structure and composition were in common use. These codes have prevented or discouraged the general use of cast iron in certain elevated temperature fields. Despite this limitation, research has continued and cast irons of controlled analysis have been developed that are structurally stable and resist deterioration at temperatures above 450° F. It is recommended that codes dealing with high temperature applications of cast iron be reviewed with the object of raising temperature limits in accordance with the demonstrated heat-resisting properties of existing grades of cast iron.

I. Introduction

PURPOSE

The present investigation and survey of the behavior of cast iron in elevated temperature engineering applications was undertaken by the War Metallurgy Committee at the request of the War Production Board with the purpose of determining whether the use of cast iron in such fields could be safely extended. A definite possibility existed that as a result of this survey the position of cast iron as an engineering material could be more sharply defined, and more strategic materials than cast iron might be conserved and procurement problems generally eased.

BACKGROUND

The project appeared justified in view of several factors. These are briefly listed as follows:

(1) General use of cast iron at high temperatures has been limited by the existence of certain codes which specify that cast iron shall not be used at temperatures over 450° F. The principal specifications, A.S.M.E. Boiler Code Specification S-13, from which other codes, such as the Unfired Pressure Vessel Code, A.S.A. Standards, etc., appear to stem, was established in 1914, 31 years ago. Reference to the Boiler Code Committee did not reveal any definite experimental basis or specific data for fixing the limiting temperatures at 450° F., and a search of the literature indicated that the only material that might have influenced code action was an A.S.M.E. Symposium held in 1909, at which it was concluded that starting at a temperature of 450° F. certain cast irons deteriorated in structure and strength to a marked degree.

Chemical Analysis

As noted in greater detail in the original report, the importance of controlling the chemical analysis of cast iron was relatively unknown at the time of this symposium, and in the few cases in which analyses and tensile properties were recorded the irons were invariably of a high carbon equivalent (now known to be generally unsuitable for high temperature pressure applications). The tensile strength of the subject irons averaged 12,000 to 16,000 psi., em-

• Abstract of War Metallurgy Committee report, WPB Survey Project SP-512. It is believed to demonstrate convincingly the fact that with our modern understanding of the metallurgy involved and ability to apply the necessary controls, gray cast iron has taken its place as a dependable material for use in exacting engineering applications. This fact has for some time been recognized by foundrymen and engineers intimately concerned with the production or use of this material, but has not been so generally recognized by designing engineers less familiar with the developments that have taken place in cast iron metallurgy.

Table 1

SUMMARY OF HIGH TEMPERATURE APPLICATIONS OF CAST IRON

Temp. Range, °F.	Destructive Factor	Applications: Successful	Applications: Unsuccessful	Total	Uses	Detailed Temp. Range, °F.	Press. Range, psi.	Life	Carbon Type	Carbon Equiv. $C + 0.3\,(Si + P)$	Alloys	Number Inoculated	Tensile Strength, psi.
451 to 600	Wear	33 (1 limited life)	0	33	Locomotive cyls., throttles, bull rings, valve boxes and bushings, steam pump cyls. and valves, Marine eng. cyls., oil pump cyls., liners, piston rings, valves, Diesel cyl. liners and pistons, aircraft piston rings.	30 at 500 or above. 8 at 600	90-1200 (22 at 200 to 300)	20,000 hr. for aircraft piston rings to 28 yr. for steam pumps. Piston rings only periodic replacement.	3 low 17 med. 8 high (old) 5 ?	3.5 to 3.9 except 8 old irons, 4.0-4.3, and Piston Rings, 4.6.	2—NiCr 1—CuMo 6—NiCrMo 1—MoNiCr	19	Modern type from 35 to 50,000 Old irons from 18 to 28,000
	Growth	15	9*	24	*Unsuccessful*—Steam valves and fittings, turbine casings and diaphragms made prior to 1920.	8 at 478 to 500 1 (600)	150 to 200	1 at 2 yr. (600° F.) 1 at 4 yr. 1 at 5 yr. 6 at 14 to 28 yr.	2 med. 4 high 3 ?	4.0-4.5	0	0	14 to 25,000 after service
					Successful — Marine engine manifolds, turbine casings, steam cyls. and diaphragms, steam chests, heat exchanger parts, locomotive steam parts.	18 at 500 or above. 3 at 600	40 to 300 (Av. 200)	New to 18 yr.—no failures.	4 low 8 med. 3 ?	3.5-3.9	1—Cu 2—NiCrMo 1—CuCrMo	8	All but 1 over 40,000 before service 2 from 33 to 35,000 after service
	Corrosion	11	0	11	Valves and fittings for crude oil.	8 over 580 2 at 600	No pressure	15 to 21 yr.—all still in use.	1 high 10 ?	Only 1 iron analyzed	1—Cr		?
	Erosion	26	0	26	Locomtive throttles, superheater headers, steam pump heads, valves and pistons, oil pump pistons, turbine control valves, Diesel engine heads and exhaust manifolds, blast furnace bells and explosion valves.	22 over 500 3 at 600	135 to 750	New to 23 yr.—all still in service.	2 low 19 med. 2 high 3 ?	3.5-3.8 except 2 old irons and 1 manifold at 4.0.	2—NiCrMo	20	35,000 min. with exception of 1 old iron at 27,000
601 to 750	Wear	26 (1 limited life)	0	26	Oil pump cyls., liners, piston valves, locomotive cyls., throttles, valves, valve chambers and cyl. bushings, steam engine cyls., Diesel cyls. and pistons, Marine engine cylinders.	22 at 650 or over, 14 at 700 or over	200 to 600	1 yr. replacement (bushing). Up to 50 yr. without failure.	8 low 12 med. 3 high 3 ?	3.6-3.9 except 3 at 4.0	2—Cr 1—Mo 1—CrMo 1—NiCr 2—NiCrMo 1—CuCrNi	15	30-45,000 Av. 40,000
	Growth	4	0	4	Turbine casings Autoclave inserts Resistance grids	2 at 650 1 at 720 1 at 750	200 ? 0	3 yr. 8 yr. 20 yr. — Still in operation.	2 low 1 ? 1 high	3.6-3.9 ? 4.3	(CuCrMo-NiCrMo) NiCr 1—Ni	0 ? 0	52,000 ? ?
	Corrosion	4 (1 limited life)	0	4	Locomotive steam pipes. Still trays and bubble caps.	4 over 700	1 at 225 3 at 0	3 over 10 yr. still in use. 1 fails by H_2SO_4.	3 med. 1 high	3 at 3.6 to 3.8 1 at 4.0	1—NiCr	1	Pressure 55,000 Nonpress. 30-35,000
	Erosion	18 (2 limited life)	0	18	Hot oil pump pistons, locomotive piping smoke box items, superheater headers and pistons, Diesel heads and pistons. Marine engine throttle valves, steam cyl. heads, bubble cap trays and spouts.	8 at 650 9 at 700 or above	200 to 275 3 no press.	New to 50 yr. without failure except trays and bubble caps fail 3-5 yr. from erosion and corrosion.	2 low 11 med. 5 ?	1 at 3.3 3.6-3.9	1—Cr 1—NiMo 2—NiCrMo	12	30 to 60,000 Av. 40,000
751 to 1000	Wear	2	0	2	Diesel exhaust valve seats and pistons.	900	?	Finally failed by wear or overloading.	1 low 1 high	? 3.9	1—CrMo 1—NiCr	1 ..	37,000 ..
	Growth	14 (2 have limited life)	0	14	Diesel exhaust valves, manifolds, furnace hangers, tuyeres and hearths, turbine valve stems, dryer heads and kettles, locomotive grate supports.	6 over 950 All over 800		8 from 5 to 15 yr. without failure. 2 replaced from 4000 hr. to 1 yr.	1 low 5 med. 5 high 3 ?	3.7-4.3	2—Cr 2—CuCr	6	30-45,000 Av. 36,000
	Corrosion	8 (2 have limited life)	0	8	Die casting equipment, lead and zinc pots, rabble arms, bubble trays.	6 at 800 to 850 1 at 900	3 from 500 to 2400 Others—0	Two limited life due to Zn and Pb—1-3 yr. Others from new to 10 yr.—no reported failures.	3 low 2 med. 2 high 1 ?	Press., 3.5-3.8 No press., 4-4.2	2—Cr 1—CuCr	4	Press. 40-50,000 Nonpress. 25-30,000
	Erosion	6 (1 limited life)	0	6	Pumps, oil valve bodies, Diesel piston heads, fuel nozzle bushings, Diesel exhaust manifold.	5 at 800 1 at 970	250-1000	1 limited. Others from new to 2 yr. without failures.	2 low 3 med. 1 high	3.4-3.8 except one at 4.2	1—CrMo	5	32-50,000
Over 1000	Wear	4 (all limited life)	0	4	Diesel bushing, liners and pistons, hot forming dies.	....	1 at 1000 3 high	Av. life 3 yr. 4000 to 10,000 parts per grind.	2 low 1 med. 1 high	3.4-3.8 3.5 4.1	(CrMo and CrMoNi) 1—CrMoCu 1—CrMoV	4	45-50,000 45,000 40,000
	Growth	13 (all limited)	1	14	Pipe covers, pots, furnace dampers, grates, trays, skid hearths, stools, retorts, exhaust manifolds.	....	No pressure	1 replaced by 30 Ni 18 Cr Longest life, 6 yr. Shortest life, 1 month.	9 low 3 med. 1 high 1 ?	3.5-4.0	4—Cr 5—CrCu 2—CrNi	13	6 at 50,000 4 at 30,000 4 ?
	Corrosion	14 (all limited)	0	14	Die casting equipment, melting pots, molds, furnace parts, cracking trays.	....	Die casting from 500-2000. Others, no pressure	From 30 days to 4 yr.	5 low 6 med. 3 high	Die, 3.6-3.8 Other, 3.6 to 4.3	2—Cr 2—CuCr 1—NiCr 1—Ni	12	Press. from 40-50,000 Nonpress. 25-50,000
	Erosion	15 (all limited)	0	15	Diesel cylinder heads, gas engine heads, hot blast valves, turbocharger rings, kiln parts, die castiig pots, dryers, furnace parts, ladles, glass molds.	....	3 from 25 to 1200. Others, no pressure	1 day to 3 yr. except gas engine heads which are still in operation after 25 yr., but are only at temp. for short periods.	5 low 5 med. 4 high 1 ?	Press., 3.4-3.8 Nonpress., 3.9-4.2	2—CrMo 1—Cu 3—NiCr 1—CrV 4—Cr 1—CuCrNi	9	Press. 38-50,000 Nonpress. from 30-50,000

*All made prior to 1920.

phasizing their inferior quality. It was found that the A.S.M.E. code has remained practically unaltered with regard to temperature limits since its inception, no cognizance having been taken of known advances in cast iron metallurgy since 1914.

(2) Committees interested in elevated temperature apparatus have already recognized the fact that with improvement in quality of cast iron, the safe maximum working temperature can be increased above 450° F. Evidence of this fact is the development of the proposed California Unfired Pressure Vessel Safety Orders recommending use of classes 20 and 25 irons at a maximum temperature of 450° F., class 30 irons at a maximum of 510° F., class 35 irons at a maximum of 575° F., and classes 40, 50 and 60 irons at a maximum of 650° F.

Applications

(3) Modern cast irons have been and are now being used in a number of engineering applications at temperatures considerably over 450° F. Obviously, certain cast irons must have been found satisfactory at such higher temperatures inasmuch as their use has been continued. However, no concerted effort has previously been made to obtain and correlate data on the general success or failure of cast irons in such high temperature applications.

(4) Many well-informed engineers in both the foundry industry and in consuming industries feel that the present code temperature limitation of 450° F. on cast iron can be safely increased. It was believed that by direct contact with these men and industries, sufficient service and experimental data might be uncovered to establish definitely the true top temperatures at which various types of cast iron can safely operate.

(5) The need for a review of the present code limitation temperature of 450° F. has been further evidenced by the recent formation of an American Foundrymen's Association Committee and a Subcommittee of A.S.T.M. Committee A-3 to study the use of cast iron at high temperatures.

In consideration of the foregoing factors, the present survey of actual applications of cast irons at elevated temperatures was immediately undertaken.

II. Factual Survey

The most significant part of the investigation is considered to be the factual survey of the success or failure of cast iron in existing high temperature applications. Specific data were obtained on 223 applications of cast iron at temperatures of over 450° F. from 99 concerns and 108 individuals, the great majority of such individuals being personally interviewed.

Forty per cent of the applications were furnished by consumers not engaged in cast iron manufacture, 30 per cent of the applications by consumer-producers, and 30 per cent of the applications by producers, or individuals connected in some manner with cast iron manufacture. The consumer-producer status was established in those cases in which cast iron constitutes a minor part of the manufactured product. For example, manufacturers of turbines and internal combustion engines who operate their own foundries were assigned this status.

The types of industries and associations included in the survey are as follows:

(1) Valve Industry
(2) Petroleum Refinery Equipment Industry
(3) Paper Industry
(4) Condenser Industry
(5) Pump Industry
(6) Furnace & Firebox Equipment Industry
(7) Power Industry
(8) Chemical Industry
(9) Alloy Producing Industry
(10) Foundry Industry & Consulting Engineers
(11) Steam Engine Industry
(12) Internal Combustion Engine Industry
(13) Army and Navy Bureaus
(14) Stoker Industry
(15) Foreign Associations (B.C.I.R.A.)

Information requested on each application included the type of casting, the analysis and method of manufacture, the temperature and service conditions to which it was exposed, the rate of failure, if any, the life of the casting, and whether it was considered successful by the consumer. Surprisingly complete information was obtained. For example, in only 39 instances, particularly of old applications, was information concerning chemical analysis completely lacking.

The data obtained are condensed in Table I. It will be noted that as a first step the applications have been empirically divided into four sections, in convenient steps of increasing temperature ranges in service. These four broad temperature ranges are 451 to 600° F., 601 to 750° F., 751 to 1000° F., and over 1001° F. The temperatures are further subdivided in the seventh column of Table I.

Second, the irons in each temperature range have been roughly classified into four groups, depending on the most probable major destruction factor; namely, wear, growth, corrosion and erosion. Obviously, either growth or mechanical deterioration from exposure to elevated temperatures could result in failure in any of these groups, but assuming that a given casting might exhibit satisfactory or indefinite life as concerns temperature effect, an estimate was made of the factor most likely to cause its final discard.

Classification

Under "Analysis," the irons in Table I were arbitrarily classified as to carbon type. They were considered "low carbon" when in the range of 2.7 to 3.1 per cent total carbon; "medium" in the range over 3.1 to 3.35 per cent total carbon; and "high carbon" if the carbon content exceeded 3.35 per cent. The most significant analysis factor related to the character and properties of unalloyed cast iron has been generally recognized as the carbon equivalent of the iron, *i.e.*, the total carbon content plus 0.3 of the sum of silicon plus phosphorus: per cent C + 0.3 (per cent Si + per cent P).

As a consequence, this value has been listed in the tables and plotted graphically in Figs. 1 and 2. It is recognized that any generalization of this type is open to exceptions, particularly when applied to extreme variations in chemical composition, but it appeared the most significant single factor in any summary treatment. The manganese in these irons generally was in the range 0.50 to 1.00 per cent, the phosphorus 0.40 per cent max., and the sulphur 0.12 per cent max.

Under "Remarks on Life" (Table I), it will be noted that a number of the applications have been in use for comparatively short periods, and obviously in these cases only the maximum life so far recorded could

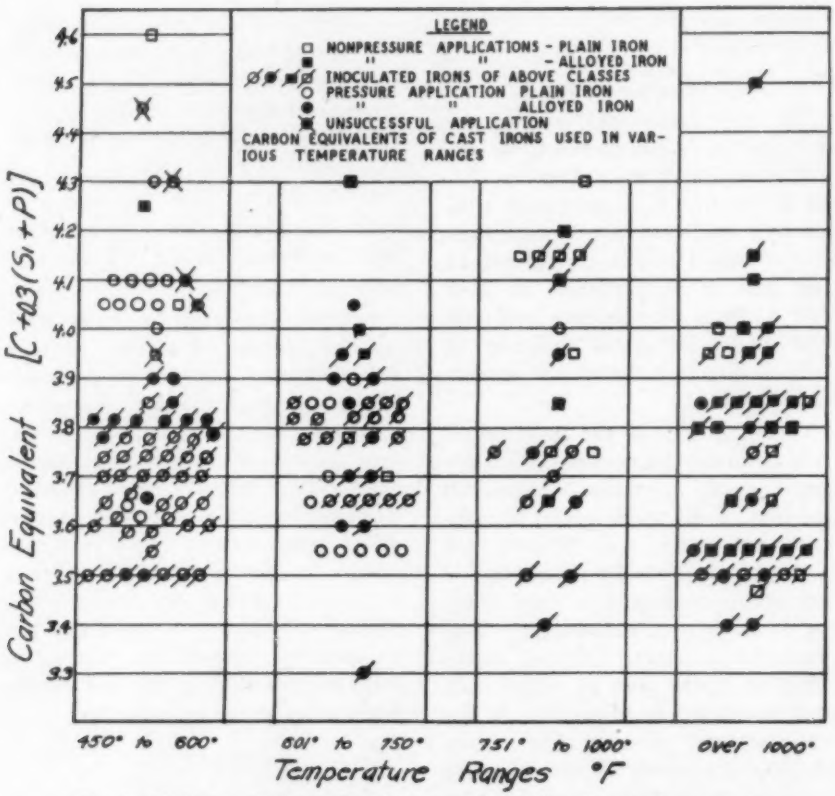


Fig. 1—Carbon equivalents of cast irons used in various temperature ranges.

be given, and a record of any failures within this period. The large number of new applications at temperatures of over 450° F. is of interest, showing that engineers are beginning to appreciate the possibilities of modern type cast irons.

Certain observations are immediately apparent from Table I and Figs. 1 and 2. In the 451 to 600° F. range, 94 applications are found, most of them involving pressure. Only nine failures are reported, and these all involve irons made before 1920 with medium or high carbon contents and with a carbon equivalent of 4.0 to 4.5 per cent. The successful applications, on the other hand, show a lower carbon equivalent of 3.5 to 3.9, with the exception of ten old type irons that run from 4.0 to 4.2 per cent.

There is a definite tendency in this temperature range, based presumably on experience, to make irons with low or medium carbon when they are intended for high temperature, pressure service. The life of the 85 successful irons extends up to 28 years, all being still in service except in the case of piston rings, which are periodically replaced because of wear.

In the 601 to 750° F. range, all 52 applications are considered successful, only four being periodically replaced due to corrosive action or excessive wear. The tendency to use low or medium-carbon irons having a carbon equivalent of 3.3 to 3.9 per cent is again evident, being most marked in applications involving pressure. Service life of up to 50 years has been reported.

In the 751 to 1000° F. range, all 30 applications are considered successful, although five have a limited life. In only one case (Diesel exhaust valves) can final failure be definitely assigned to growth or change in dimensions. Again there is a tendency to use low or medium-carbon irons, a carbon equivalent of 3.4 to 3.8 per cent being used in the case of castings that must resist pressure. Service life up to 15 years is reported.

Although this survey was directed primarily to applications operating under 1000° F., some 47 instances of the use of cast iron in excess of this temperature were reported. Forty-six applications were considered successful and one unsuccessful. In contrast to the lower temperature applications, the life at temperatures of 1000° F. or over was limited in all cases. In one case a life of one day was recorded, but the application was considered successful in view of the comparable behavior of competitive materials. The maximum life recorded for one application in this group was 6 years.

No continuous pressure was en-

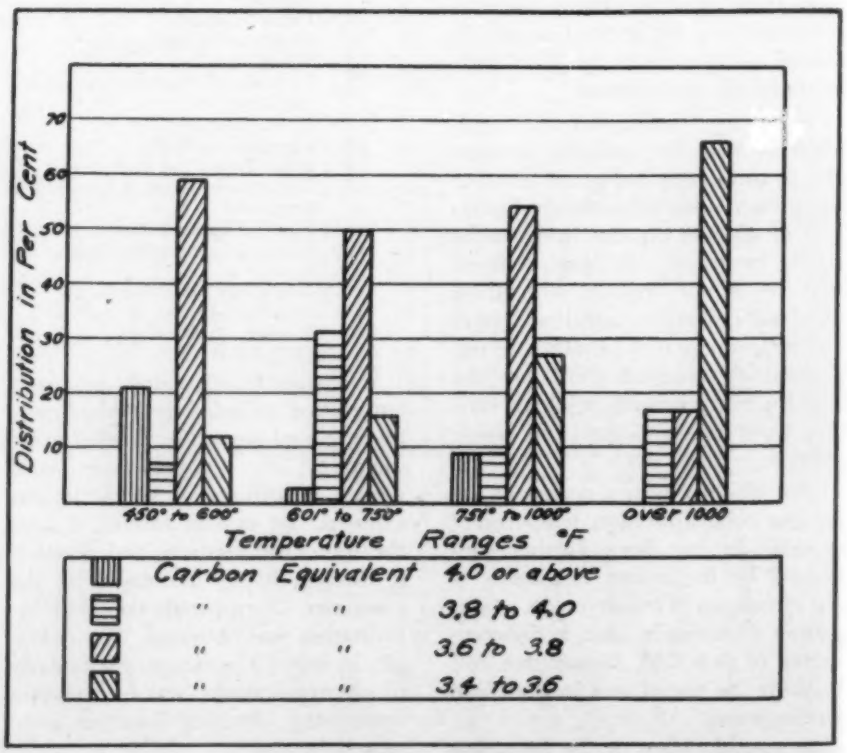


Fig. 2—Carbon equivalent distribution of irons used to resist pressure in various temperature ranges.

countered, but compressive loading existed in the case of hot-forming dies, die casting equipment, and Diesel parts with skin temperatures over 1000° F. When strength is a factor, there is again a tendency to use low or medium-carbon irons with a carbon equivalent range of 3.4 to 3.8 per cent.

Certain other observations are significant. With regard to tensile strength, virtually all of the modern irons in the 451-600° F. range have a minimum tensile strength of 35,000 psi., and most of the successful older irons possess a strength in excess of 30,000 psi. This also is true in the three other temperature ranges in which a definite tendency to hold modern irons to a 30,000 psi. minimum is apparent, with the average tensile strength approximately 40,000 psi.

Ladle Inoculation

A surprisingly large number of the cast irons investigated were inoculated in the ladle. Forty-seven of the 94 irons in the 451 to 600° F. range, 29 of 52 in the 601 to 750° F. range, 16 of 30 in the 751 to 1000° F. range, and 38 of 47 in the range over 1000° F. are known to have been ladle-treated. Thus, approximately 58 per cent of the total irons were subjected to some type of ladle inoculation. If the irons of unknown analysis are omitted, the inoculated irons constitute 73 per cent of the remainder. Various inoculants were employed.

With regard to the addition of special alloying elements, interest was mainly confined to low alloy gray cast irons, *i.e.*, irons containing a maximum of about 2.5 per cent of any special alloying agent. The special alloying elements included chromium, nickel, copper, molybdenum and vanadium, used either alone or in combination.

It can be noted from Table I that in the 451 to 600° F. range, 17 out of 94 irons are alloyed. In the 601 to 750° F. range, 17 out of 52 irons are alloyed. In the range 751 to 1000° F., 10 out of 30 are alloyed, and in the range of over 1000° F., 33 out of 47 irons are alloyed. Thus, about 34 per cent of the total irons are known to be alloyed. If irons of unknown analysis are eliminated, alloyed irons constitute 43 per cent of the remainder.

The tendency to employ low-alloy irons as temperature conditions become more severe is brought out in Fig. 3. Chromium is the most common alloying agent, appearing in 91 per cent of the alloyed irons, whereas nickel appears in 44 per cent, molybdenum in 39 per cent, copper in 23 per cent and vanadium in approximately 3 per cent of the alloyed irons.

In comparison with the above findings, information from the British Cast Iron Research Association is of interest in that, possibly due to wartime shortages or the fact that they did not differentiate between pressure and non-pressure applications, they appeared quite liberal in their permissible upper temperature limits.

According to British advices, ordinary cast iron may be used at temperatures up to 840° F. (450° C.), and an all-pearlitic, close-grained iron, preferably of a low-alloy type, may be safely used at temperatures up to 1020° F. (550° C.). If as much as 1 per cent of chromium can be incorporated in the iron, the upper temperature limit is raised to 1110° F. (600° C.). Low alloy iron is preferred to unalloyed iron for high temperature work, being considered more heat resistant, "partly as the irons are usually better made, more homogeneous, more uniform, and closer-grained."

Chromium carbide is stated to be particularly important as conferring stability, and if the amount of chromium is limited due to its tendency to make the iron white, nickel is recommended to permit further increase in chromium content, for example, in the ratio 3 Ni:1 Cr.

III. Research Data on Behavior of Cast Iron at Elevated Temperatures

Considerable unpublished research data on the behavior of cast iron in the temperature range of 450 to 1000° F. were obtained in the course of the survey, and a summary of this information in conjunction with published data on the effect of high temperatures on the strength, growth, and structural stability of cast iron is included in the present report.

Strength

A large part of the laboratory information dealt with the short-time high temperature strength of cast irons varying in carbon equivalent from 3.6 to 4.5 per cent, and the test results showed no appreciable falling off in tensile strength up to 750° F. At temperatures above 1000° F., the tensile strength in general decreases rapidly.

Creep or long-time temperature tensile tests of cast iron are, of course, more significant, but data on such tests are limited. The available creep tests are reassuring, however,

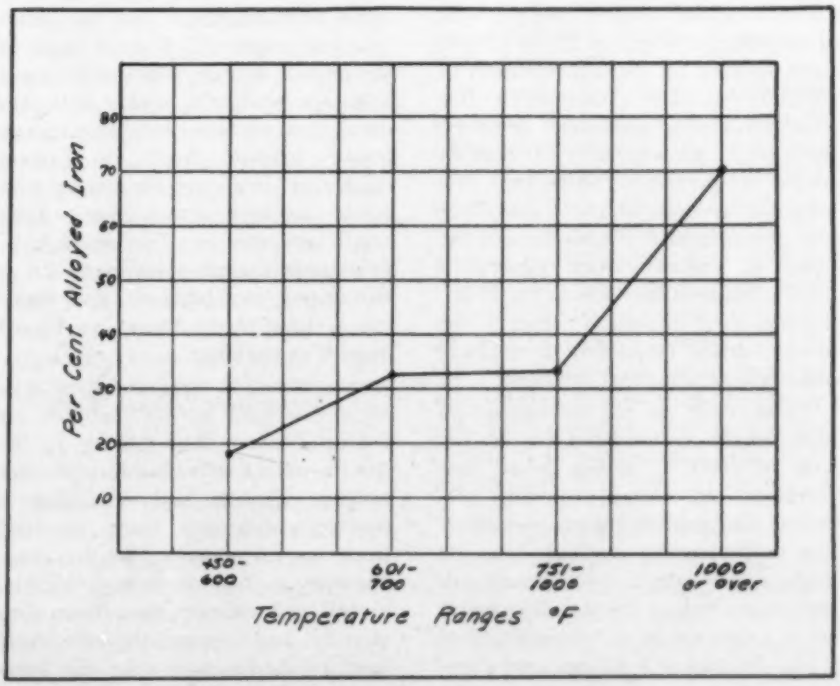


Fig. 3—Percentage of irons known to be alloyed in each of the various temperature ranges.

in that they demonstrate that ordinary cast iron (up to at least a carbon equivalent of 3.95 per cent) can resist loads of approximately 10,000 psi. at 750° F. without exceeding a creep rate of 1 per cent in 10,000 hours. The use of small percentages of alloying elements in cast iron has been found to increase materially the resistance to creep.

Before leaving the subject of the high temperature strength of cast iron, it should be observed that a critical exposure temperature exists for ordinary cast irons which, if exceeded, will produce a progressive loss in room temperature strength, due to such factors as growth, oxidation, and structural alteration. The minimum temperature at which such strength reduction may occur is a function of the structural stability or growth resistance of the particular iron, which according to evidence obtained in the survey is in turn a function of the carbon equivalent of unalloyed cast iron.

Superheated Steam

For example, records were found of iron castings subjected to superheated steam for extended periods at a temperature of 478 to 488° F. The irons having a carbon equivalent of 3.6 per cent exhibited an average strength of 33,000 psi. and a pearlitic structure after 14 years of such exposure, while castings with a carbon equivalent of 4.3 to 4.4 per cent showed an average strength of 16,200 psi. and a completely ferritic structure, and were removed because of growth after 10 and 14 years, respectively. Although the original strength of these irons was not determined, it is obvious that the irons of higher carbon equivalent have a dangerously low strength following their exposure, whereas the lower carbon equivalent irons have maintained a normal strength.

Data exist in the literature on tests made at temperatures in excess of 1000° F. which prove that additions of certain alloying elements also provide means of inhibiting or preventing strength loss. As little as 0.50 per cent chromium will materially reduce the loss in strength after exposure to a temperature of 1472° F., and at a 1.5 per cent chromium level no reduction in strength was observed in a gray iron after 500 hours' exposure to this temperature.

GROWTH

The tendency of certain cast irons to grow or permanently increase in dimensions on exposure to temperatures above a critical level is well known. The minimum temperature at which this phenomenon first appears is again a function of the structural stability of the particular iron. This growth phenomenon, besides producing dimensional changes, is also believed to lead to surface cracking and permanent strength loss, and thus often is the principal factor that leads to final failure of a casting at elevated temperatures.

Unfortunately for the purpose of this survey, most of the growth measurements have been made at temperatures of 900° F. or over. This is understandable in view of the fact that below this temperature the growth is very small in a given period of time, thus complicating the test procedure and greatly extending the necessary exposure time. However, considerable growth data at temperatures of over 900° F. have been accumulated and have demonstrated that unalloyed cast irons of low carbon equivalent are more resistant to growth than those of high carbon equivalent.

A number of general comments in regard to the character of these irons were received and are herewith summarized. Use of steel in the cupola mixture from which such irons are produced, insofar as it produces a more dense iron, apparently retards growth. Such low carbon equivalent irons are frequently subjected to ladle inoculation. Even small amounts of alloying agents, principally carbide stabilizers such as chromium, molybdenum, and vanadium, have been found to retard growth materially.

Comparative Growth Tests

Unpublished data relative to the specific effect of chromium on decreasing growth and stabilizing a pearlitic structure were received from several sources. In the comparative growth tests available, nickel and copper have been frequently and apparently effectively used in conjunction with the foregoing carbide stabilizers. It is obvious from the present survey that information of this type is being utilized to a considerable degree in the production of modern heat-resisting cast irons.

The difficulties inherent in tests directed toward determination of growth characteristics of cast irons at temperatures below 1000° F. are emphasized by the only research investigation of this type uncovered in the survey. In this test 36 unalloyed and low alloy cast iron bars ¾-in. in dimaeter and 21 to 23 in. long were submitted to superheated steam at 750° F. for periods varying from about 1 year to 995 days. In considering the resulting data, it should be first noted that the changes in length are generally minute, and consequently length changes brought about by stress relief and even by corrosion at room temperature may and apparently do seriously affect the growth readings.

Rate of Growth

However, assuming that all dimensional changes were due to growth, it is of interest that with one exception (a 0.15 per cent growth per year of a cast iron of 3.8 per cent carbon equivalent removed before completion of the test) all the irons with carbon equivalents of 3.95 per cent or under and tested in the "as-cast" condition or after an anneal not exceeding 1112° F. (600° F.), exhibit a total growth of less than 0.10 per cent a year *i.e.*, a length increase of 0.02 in. or less in 20 in.).

A majority show growth of under 0.05 per cent a year (a length increase of less than 0.01 in. in a 20-in. length during a one-year exposure). After certain periods, for example, 534 hours, 455 hours and 901 hours, respectively, in three different tests, the reported growth decreases rapidly to about one-half or less that reported in earlier periods.

Although length changes of such minute amounts do not permit accurate gauging of the effect of low alloy additions in these growth resistant irons, certain broad trends can be observed. For example, when the carbon equivalent exceeds approximately 4.0 per cent a very marked increase in the growth of unalloyed irons was recorded.

An unalloyed soft iron with a carbon equivalent of 4.14 per cent and exhibiting free ferrite as cast,

showed a growth in excess of 3.0 per cent a year, accompanied by marked internal oxidation. That such excessive growth can be materially reduced even in high carbon equivalent irons by additions of alloys, such as chromium and molybdenum, was evidenced by a drop to 0.25 per cent growth per year in an iron of 4.34 per cent carbon equivalent, containing 0.39 per cent chromium and 0.51 per cent molybdenum.

Annealing Temperatures

A second observation was that if unalloyed irons were annealed at temperatures of 1562 to 1607° F. (850 to 875° C.) previous to exposure to growth tests at 750° F., excessive growth took place despite an originally low carbon equivalent (3.48 per cent) and a previous record of excellent growth resistance in the as-cast condition. In this case the high annealing temperature caused the original structure to completely transform from pearlite to ferrite.

The only alloying agent used in conjunction with such high annealing temperatures was molybdenum, and in quantities of 0.35 to 1.0 per cent it appeared very materially to decrease the adverse effect of high annealing temperatures on growth resistance and to delay pearlite decomposition. Other carbide-stabilizing alloys, such as chromium and vanadium, would be expected to have a similar effect.

An obvious conclusion from the foregoing data is that the presence of ferrite in the structure of a cast iron, whether produced by using a high carbon equivalent or by annealing an iron of lower carbon equivalent, seriously lowers the ability of an iron to resist growth. The use of small amounts of alloying elements appears to counteract such increased tendency to grow insofar as they stabilize the pearlitic structure and prevent separation of ferrite.

In general, these tests indicate that dimensional changes of cast iron in superheated steam at 750° F. can be held to very low values by proper analysis control.

Thermal Shock

No direct research data on the resistance of cast iron to thermal shock were encountered during the present survey. The subject is introduced at this point, however, because several engineers contacted in the course of this survey expressed concern regarding this property of cast iron. There appeared to exist some uncertainty as to whether cast iron would withstand sharp thermal gradients through a given section to the same degree as steel, possibly due to a belief that thermal shock resistance may be associated in some manner with ductility exhibited in a tensile test.

Representatives of the valve and oil industry also inquired as to whether cast iron parts brought to a red heat due to accidental fire could be rapidly quenched with water or carbon dioxide without cracking. These inquiries suggest the possibility that failure of cast iron parts has occurred following such accidental fires, but no definite information on such occurrences could be obtained, or estimates as to the comparative resistance of alternate materials, such as steel, to a similar set of conditions.

Thermal Shock Resistance

On the subject of thermal shock resistance, it is known from the present survey, as well as from records of heat-treated parts, such as cylinder liners, that (1) cast iron parts can be successfully quenched from temperatures above the critical point; (2) that cast iron is successfully used in internal combustion engines, furnace parts, pots and molds in which sharp temperature gradients normally exist, and (3) that, more recently, cast iron has been adopted as tapping pots for molten metals heated to temperatures in excess of those used in steel manufacture. One contributor to the survey specifically stated that under temperature of 1000° F. he considered the thermal shock resistance of cast iron to be satisfactory inasmuch as he regularly heated castings of sharply varying section, such as cross heads, to 760° F., and quenched them in cold brine without ill effects.

However, information on the general subject of thermal shock resistance of cast iron is admittedly limited, and inherent shock resistance will no doubt vary, as in the case of steel, with the type of cast iron. In further investigation of the subject, it will be necessary to differentiate between failures due to thermal shock, and failures due to gradual development of growth cracks that may result from prolonged exposure of irons of unsuitable carbon equivalent to excessively high temperatures.

IV. Consumer and Producer Reaction to Use of Cast Irons at High Temperatures

In the course of the survey, opinions were obtained from manufacturers and users as to the desirability of employing cast iron at temperatures above 450° F. These reactions are an important part of the survey and hence are summarized here. In considering the following remarks, the difficulties and limitations attendant on crystallizing the diverse opinions of many men from different fields into a few paragraphs should be borne in mind.

It was found in the course of the survey that a surprising unanimity of opinion exists as to desirability of raising the present code temperature above 450° F. Differences of opinion were encountered as to the exact maximum temperature that should be established, the suggested safe working temperatures in the range of 550 to 800° F. The majority selected maximum safe working temperatures in the range of 600 to 750° F. In the few cases (four in all) in which the present code limitation of 450° F. was considered adequate, the individuals based their conclusions entirely on tests or experience dating at least 20 years or more ago.

In most cases these individuals qualified their remarks by stating that experience with modern or low alloy irons might alter their conclusions, but that such experience was lacking due to the existence of the present code limitation of 450° F. When an increase in the code temperature was recommended, it was almost invariably accompanied by the statement that some type of specification should be set up to assure the consumer that he was receiving an iron suitable for high temperature use.

Suggested Specifications

The suggested specifications included (1) establishing a minimum tensile strength for irons to be used within certain temperature ranges; (2) establishing a preferred chemical analysis with the purpose of controlling carbon equivalent; and

(3) establishing foundry requirements covering minimum percentages of steel to be used in the furnace charges, addition of special alloys and the use of ladle inoculation. By far the most commonly suggested specification was based on tensile strength alone, a minimum of 40,000 psi. usually being recommended for irons used at temperatures of 600° F. or above.

Alloyed Cast Irons

If an alloyed iron is employed, *i.e.*, an iron containing small amounts of one or more of the elements chromium, molybdenum or vanadium, or these elements in combination with nickel or copper, there is a general tendency among engineers to extend the allowable temperature limits above those employed for unalloyed irons. It will be recalled from information received from the British Cast Iron Research Association that this tendency also is evident in British practice.

It should not be assumed from the foregoing that problems specific to certain industries and not directly connected with high temperature resistance may not limit the use of cast iron. For example, in the oil industry, although successful use of cast iron valves and fittings at temperatures up to 800° F. is believed feasible and has, in fact, been practiced in several instances, doubt is felt as to the advisability of using this material in lines carrying hot oil under high pressure. Failure from thermal shock in case of a fire is considered to impose too great a risk.

In the valve industry opinion is divided as to the feasibility of using cast iron valves in certain industries, although all manufacturers believe the present temperature limit of 450° F. can be raised at least 100° F. when using controlled cast irons. Proper pipe layout, such as the use of ball-and-socket joints, "L" joints, or expansion joints to avoid excessive or uneven loading, is considered important when cast iron valves or fittings are employed.

High Strength Level

The advantages of holding cast irons to a high strength level in such applications are at once apparent. In valves where stresses in excess of the strength of cast iron structures may be encountered, and where it is important that eventual failure take place by distortion or bending rather than cracking, steel should be selected.

In steam applications, certain turbine manufacturers successfully employ high strength and low alloy cast irons for casings, diaphragms and steam chests at temperatures up to 650° F., although a more conservative attitude is exhibited by some of the larger manufacturers pending code changes. One producer, on the basis of tests reportedly made in France about 20 years ago, uses cast iron only in exhaust lines.

Steam Engines

Records of the behavior of steam engines, specifically of the locomotive type, proved to be one of the most fruitful sources of information. The universal and successful use of cast iron in such applications at temperatures as high as 750° F. and under 250 psi. constituted, in the opinion of many engineers, the best possible proof that the present low temperature limitation on cast iron is not justified.

Marine steam engines now employ cast iron at temperatures up to 650° F. and 240 psi., and no difficulty has been reported from its use. The sections employed are rather heavy, but no marked or destructive growth has been experienced. The data are sufficiently conclusive to have resulted in recent marked liberalization of the attitude of government agencies towards the use of cast iron in high temperature marine propulsion engines.

Internal Combustion Engines

In the case of internal combustion engines, a very liberal attitude was evident regarding the use of cast iron. Cast iron parts operating at temperatures of 1000° F. and with skin temperatures exceeding this figure were encountered, and parts operating continuously at temperatures up to 750° F. were common. Many of these parts show marked temperature gradients since they are usually water cooled. No growth or trouble was reported by the manufacturer during the expected life of the engine except from accidental factors, such as overloading.

Foundrymen associated with foundries capable of producing controlled cast irons were generally of the belief, based on reports of consumers, that the temperature limitation could be safely increased to at least 650° F. They expressed full confidence in their ability to produce, regularly, irons to meet such temperature conditions.

V. Conclusions

(1) Successful use of cast iron of controlled analysis in a wide variety of temperature applications demonstrates that there is no justification for continuing the present arbitrary temperature limitation of 450° F. for all cast irons, as originally established by the A.S.M.E. Code Committee in 1914.

(2) It is evident from the record of 233 applications above 450° F. that cast irons of controlled analysis can be safely employed in many pressure applications at temperatures considerably in excess of 450° F.

(3) From the survey record, it is evident that cast iron parts of controlled analysis are being successfully used in pressure applications at temperatures as high as 750° F. with indefinite life, or with a life limited by other factors than heat resistance.

(4) Out of the 233 applications on which records could be obtained, only nine failures due to heat effects were reported. Each of these nine failures is limited to cast irons made prior to 1920, and in all of the cases in which analyses of the unsuccessful irons are known, the carbon equivalent, per cent C + 0.3 (per cent Si + per cent P), was found to be 4.0 per cent or above. A number of castings showed limited life as the service temperature exceeded 750° F., but were considered successful by the users inasmuch as final failure was reported to be due to factors not connected with the inherent heat resistance of cast iron.

High Temperature Pressure Applications

(5) In the production of cast irons for high temperature pressure applications, a definite tendency has been shown to hold the total carbon content to a low or medium value (2.7 to 3.35 per cent) and the carbon equivalent in the range of 3.4 to 3.9 per cent. The majority of successful applications were made from cast irons lying within this analysis range.

(6) It is evident from the recorded failures and existing research findings that unalloyed open-grained

irons of a carbon equivalent of 4.0 per cent or above are normally not suited for high temperature pressure or steam applications.

(7) From the survey records, it is evident that for successful heat resistance it is advisable to hold the tensile strength of cast irons to a minimum of 35,000 psi., with the average minimum tensile strength approximating 40,000 psi.

(8) Ladle inoculation is widely employed in irons used for high temperature applications. At least 58 per cent of the irons covered in the survey are known to have received some type of ladle inoculation.

Low Alloy Cast Irons

(9) About 34 per cent of the irons covered in the survey are of the low-alloy type, *i.e.,* they have received small additions (up to 2.5 per cent) of one or more of the elements chromium, nickel, copper, molybdenum, and vanadium. The number of alloyed irons increases with the severity of the temperature conditions. Chromium is the most common alloying element, appearing in 91 per cent of the alloyed irons.

(10) Records of experimental work received in the course of the survey show that in "short-time" tensile tests the normal strength of cast iron is maintained up to a temperature of at least 750° F. Available creep test data indicate that cast iron (up to at least a carbon equivalent of 3.9 per cent) can resist loads of approximately 10,000 psi. at 750° F. without exceeding a creep rate of 1 per cent in 10,000 hours.

(11) Records of research work and service exposure tests indicate that the presence of free ferrite in an alloyed iron (whether the ferrite is produced as cast by using a high carbon equivalent or produced by annealing an iron of lower carbon equivalent) seriously lowers the ability of an iron to resist growth.

Chromium Additions

(12) Unpublished research records from several sources were received in the course of the survey with reference to the effect of small chromium additions on decreasing growth. The use of chromium as well as other alloying elements, either alone or conjointly, is recommended by these contributors. These findings are in accord with published information, and the use of small amounts of alloying elements in cast iron would, therefore, appear advisable, at least to the extent that they stabilize a pearlitic structure and minimize separation of free ferrite.

VI. Recommendations

The authors of the present report have been asked to offer general recommendations on the basis of material received in the course of the survey and interviews held with producers and consumers. However, it is realized that no attempt should be made to usurp the functions of code bodies whose legitimate business it is to fix allowable temperature limits and determine specifications.

It can be stated, solely on the basis of the factual survey, that cast irons of controlled analysis can be and are successfully employed in commercial pressure applications at temperatures up to at least 750° F. On the basis of research findings, such irons also retain a large proportion of their strength and structural stability up to this temperature. In view of these findings, the present arbitrary limiting temperature of 450° F. set by the A.S.M.E. Boiler Code and other code bodies for all cast irons irrespective of type, does not appear justifiable.

It is recommended that any cast iron intended for high temperature applications be required to meet definite specifications. On the basis of this survey, unalloyed or low-alloy cast irons normally should be of low or medium carbon content, and possess a maximum carbon equivalent of about 3.9 per cent. Use of carbon equivalents above this maximum would appear to be justified only in the case of highly alloyed irons.

Ladle inoculation enters this picture insofar as it will beneficiate the structures obtained with low carbon equivalent irons. The cast irons should be required to meet a minimum tensile specification; for example, 35,000 psi. in the case of irons used in the neighborhood of 450° F., and progressively stronger irons for use at higher temperatures. The belief that tensile strength can be used as a major criterion is widespread, as evidenced by the proposed California Unfired Pressure Vessel Safety Orders and the reactions of many individuals contacted in the course of the survey.

The use of small percentages of added alloying elements that stabilize a pearlitic structure appears advisable under severe temperature conditions, or to assure heat resistance in critical applications.

The information obtained indicated that the use of cast iron can be safely extended in high temperature fields. However, the authors strongly feel that on the basis of this survey, cast iron should not be promiscuously substituted for other materials. Each installation should be carefully reviewed to be sure that some property other than heat resistance may not be the final determining factor.

CENTRIFUGAL CASTING

Committee Studies Casting Methods

By Chairman D. Basch, General Electric Co., Schenectady, N. Y.

THE Committee on Centrifugal Casting was constituted at the 1944 meeting of the A.F.A. Aluminum and Magnesium Division.

The task allotted to this committee was to investigate the possibilities of centrifugal casting light metals—aluminum and magnesium. Another duty involved obtaining for the light metals industry the same advantages that have accrued to such a large extent in steels, cast iron and the brasses.

At the first committee meeting, held in Cleveland, representatives of the foundry industry, suppliers, machine builders and presumptive consumers of light metal centrifugal castings were present. This meeting was called to obtain opinions and discuss new ideas.

Possibilities Evident

It became evident that the possibilities of light metals for centrifugal castings were quite definite, and that the advantages would be outstanding. No particular action was taken, but everybody was asked to collect whatever information was available and to formulate in their own mind some ideas as to how the work should be handled.

The second meeting took place in Detroit, and it soon became evident, in the discussion, that there was no agreement as to the basic principles to be followed. While there seemed to be agreement as to the feasibility of centrifugal casting of light metals, the ideas as to what must be done to produce centrifugal castings were widely divergent. Fortunately, the chairman had been able to lay his hands on confidential reports on centrifugal casting of light metals issued by the British Armament Research Department, which is the counterpart of the American War Metallurgy Board. The British apparently have done a tremendous amount of work in investigating the light metal centrifugal casting process and have been able to transform some very definite recommendations as to the best manufacturing routine using these light metals.

The English report claims that aluminum and magnesium can be cast centrifugally to be free from oxide inclusions and of a dense, fine grain structure without undue segregation. Also that the physical properties exceed those of ordinary sand castings and with yields, i.e., the ratio of net and gross weight, considerably above that of sand castings.

Use British Pattern

It was agreed that if the recommendations of the British Armament Research Department could be proven to be valid we would have a firm basis for further development. It was further decided to use a pattern corresponding, in the main, to the same design as that employed by the BARD. This pattern was to be used for test purposes, a certain number of castings in aluminum and magnesium following the manufacturing routine by the British.

The proposed casting is a wheel about 13-in. diameter, weighing about 20 lb. when made from aluminum, and is a combination of a centrifugal and a centrifugal casting.

A group of plants agreed to produce, in a vertical machine, three centrifugal castings each of the variations of the pattern. (The variations consisting simply in different thicknesses of the spokes connecting the hub of the casting to the rim.)

A similar group agreed to make the corresponding number of magnesium alloy centrifugal castings.

One plant agreed to make the same number of aluminum and magnesium castings in sand for comparison with the centrifugal castings.

Another plant decided to produce the same number of castings in permanent molds; while another undertook the production of magnesium castings in graphite (as the nearest approach to metal mold).

In order to make sure that all castings, whether made centrifugally or statically, use exactly the same metal, the aluminum and magnesium is to be taken from the same stockpiles. For a similar reason it was arranged with one concern to undertake the heat treating of all castings, and with another firm to do all the x-raying of the castings.

After heat treatment and x-raying, test bars will be cut out of each casting, at strategic locations, to determine tensile, yield strength and elongation. Analysis also will be taken at various points of the castings to investigate the changes in composition, segregation, etc. The physical testing has already been arranged for through the generous help of the committee members who have the testing equipment and personnel.

Grain size will be checked.

All data will be coordinated and finally evaluated by the plenary committee.

The job is progressing, the material has been distributed, patterns have been made, and we may expect castings in the not too far distant future.

Of course, under present conditions of manpower shortage and production demands the program cannot progress as fast as it would ordinarily. The interest in the program, however, seems to be so general and the advantages to be realized, both commercial and mechanical, so evident, that the work is actually progressing faster than we had expected.

Some Results

Some isolated tests run in the meantime have brought out the following points: (1) The yield of aluminum centrifugal castings is on the order of 70-80 per cent (higher in the case of stack molding) against about 25 per cent in sand. (2) The yield of magnesium centrifugal castings is again about 70-80 per cent (higher in the case of stack molding) against about 20 per cent in sand. (3) The fear of the danger of oxide inclusions in aluminum and magnesium due to the weight of aluminum and magnesium oxides compared with the base metal does not seem to be borne out by actual tests. (4) Castings made so far in-

dicate dense, fine grain structure with high physical properties. (5) Stack molding, i.e., stacking cores on top of each other with one common through sprue, seems to be quite feasible.

Acknowledgments

To the following the committee wishes to extend its thanks for the cooperation and time given in this study: Ford Motor Co. of Canada, Ltd., Windsor, Ont.; Naval Research Laboratory, Anacostia Station, Washington, D. C.; Shenango-Penn Mold Co., Dover, Ohio; General Electric Co., Schenectady, N. Y.; Michigan Light Alloys Corp., Grand Rapids, Mich.; Eclipse-Pioneer Div., Bendix Aviation Corp., Teterboro, N. J.; Reynolds Metal Co., Springfield, Mass.; Maryland Sanitary Mfg. Corp., Baltimore, Md.; National Smelting Co., Cleveland; and Doehler-Jarvis Corp., Batavia, N. Y. The committee also desires to thank the Aluminum Co. of America, National Carbon Co. and Dow Chemical Co. for services rendered. The valued assistance of Peter Blackwood and John Perkins, Ford Motor Co. of Canada, Ltd., and C. E. Nelson, Dow Chemical Co., was greatly appreciated by the committee.

COMMITTEE REPORT ON

The Foundry Sand Research Project

By Technical Director H. Ries, Ithaca, N. Y.

IN spite of the pressure of work due to war conditions, most of our sand research committees have continued active during the past year.

The testing of sands at elevated temperatures has assumed such importance that it was found necessary to form three subcommittees, dealing with steel, iron and nonferrous sands, respectively, and the first of these subcommittees has been particularly active. The results of this work are appearing as reports of D. C. Williams, Sand Research Fellow.

Methods Being Developed

The Subcommittee on Physical Properties of Steel Foundry Sand at Elevated Temperatures has spent much time developing the proper methods of testing sand at elevated temperatures, and establishing the requisite conditions of testing and furnace construction to produce reliable, uniform and comparable results. It is surprising to find how many factors enter into the problem, and each must be given careful consideration. These high temperature tests are in some cases used for sand control work and in others for research experiments. It is to be hoped that they will be used more for the former when better understood.

The Committee on Grading and Fineness is giving attention to the method of expressing fineness by cumulative curves, instead of plotting individual percentages. It also is considering the use of the hydrometer for separating the constituents of the A.F.A. clay, which will be found to be of importance.

Another important property needing more attention is that of green deformation. Foundrymen have not given it much attention and have not realized its importance. They have sometimes complained of the inconsistent results obtained. W. G. Parker, chairman, Committee on Deformation, has devised a mechanism which makes the test more reliable, and his committee should have information of interest to present in the not distant future.

The Core Test Committee has a number of problems which it is investigating, such as warm strength and moisture absorption tests, collapsibility, core washes, core gas, etc. These have been assigned to subcommittees of the main committee and will be reported on at a later date.

The Light Metals Committee still has much work ahead of it studying first shop mixtures and their properties and perhaps special methods of testing. As Chairman Brewster states, references in the literature are quite old and scanty.

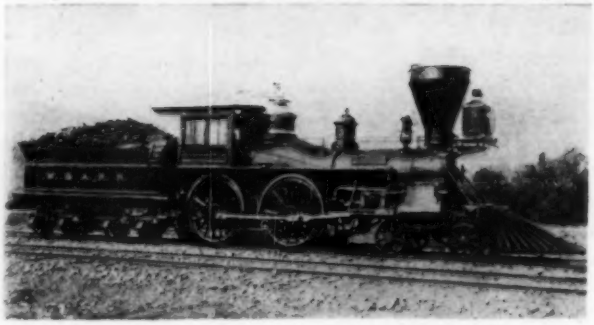
Another committee, that on Green Sand Properties, is studying the present tests on green sand to see what improvements in them may be necessary.

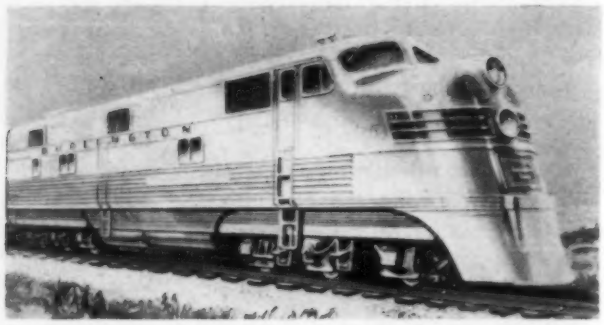
Two committees which have been inactive for the duration are those on Durability and Flowability. We are particularly in need of a standard and suitable method for testing the latter, as some foundrymen claim that existing suggested methods do not help them.

There is no doubt that the additional routine work imposed by the war has caused a slowing down in some cases of sand research. This is unfortunate, because there is still much to be done.

The Chairman finds that important and interesting work which has never been published has been done in some foundry laboratories, and it would be informative and of value if, when such results are obtained, they could be made public. In some cases this work involves tests which hitherto have not been generally tried.

The use of sand control has become widespread and foundrymen are appreciating it more and more. Cases are found where there is difficulty in applying it to foundry practice, but it should be emphasized that the tests should be carried out in accordance with instructions to obtain reliable results. Furthermore, the results obtained in these tests should be carefully checked with results obtained in the foundry.





Two types of passenger locomotives are shown above. The extreme differences are quite apparent. Will the locomotive of tomorrow require more castings or will plastics, welding, metal stampings, forgings or powder metallurgy play a larger part than normally?

The POST-WAR Outlook for the Foundry Industry

By E. F. Platt,
Castings Buyer, Sperry Gyroscope Co., Brooklyn, N. Y.

• ***This paper, while recognizing the technical advances and war production records of the foundries, emphasizes the need for intelligent cooperation within the industry to meet the problems of post-war competition.***

DURING 1943 Arthur J. Tuscany, Executive Secretary, Foundry Equipment Manufacturers Association, made the following statement: "The foundries of this country have made a much larger contribution to the war effort than they themselves appreciate or realize."

In the Dec. 1944 issue of *The Foundry,* the editor discussed the excellent record established by foundries during the first year of the war, and concluded with the statement that "an industry which has been able to establish such a fine record should render even greater service in the days to come."

For the purpose of comparison, a few examples of some of the things which have recently confronted foundry operators should be mentioned.

During the time it has been the author's pleasure to serve on the A.F.A. Inspection of Castings Committee, he has come to recognize that buyers of castings, as well as foundries, have their shortcomings. The author should like everyone to understand that, as far as he is concerned (and he is sure that other buyers of castings feel likewise), anything which can be done to bring about closer cooperation between foundries and buyers of castings, in the trying days ahead, will be carefully considered by the members of this Committee.

Foundry Reconversion Period

It would be presumptuous for any individual to attempt to answer even some of the many questions which are being asked from day to day as to the future for the foundry industry. Nevertheless, the shape of things to come is, to the author's eyes, clearly evident.

The dedication of practically our country's entire industrial machine to the prosecution of the war is now complete. Even with the shift of things required by our armed forces of various and sundry types, there is an obvious lag. No one knows how long the accent on war manufacture will continue any more than anyone knows when the war will end. However, we can feel reasonable sure of one thing and that is, when the war does end (and it is sincerely hoped that that day is not far off), a reconversion period will confront all of us.

The author is one who feels that it will not take much more time to reconvert than it did to get under way for war manufacture. The pressure of civilian requirements is likely to be great, although of a different character.

We know now that the nation at large is going to be starved for machines and gadgets of all types. Our transportation system, from railroads to automobiles, will be pretty well worn out. And we suspect that every man returning from service in our armed forces will want to get aboard something and go some place.

It seems logical to expect that the automobile industry will reconvert first, with probably little immediate change in their first models. They will probably make use of their old machine tools and start manufactur-

ing early in order to satisfy the appetite for new orders. The same thing will apply to thousands of machines, such as refrigerators, vacuum cleaners, washing machines, furnaces, kitchen equipment, etc., and private utilities are going to need pumps, pipes, turbines, generators, and no end of other equipment.

Agricultural Machines Needed

Last, but by no means least, our farm trade will need new agricultural machines in untold quantities. Summing all this up, the outlook for the foundry industry, to say the least, is encouraging. There will be demands for all types of goods. Large interests will have huge plants and increased funds.

The demands for repair parts for all types of machines will be noticeable, and this latter demand could have the effect of shifting more of this business out of the foundries that will be required to run full capacity on new work.

Now, here is an important point—in the foundry industry, we shall see a very large increase in the capacity for manufacturing light, non-ferrous castings. However, among competing industries, there will be a large capacity for producing forgings. Plastics in many forms will be offered, and the new combination of wood and plastics will prove to be more competition for foundries.

All of the government training which has been under way during this war, and which makes "Winnie" a welder in two months, has given a lot of good publicity to the welding process, and the emphasis on aircraft, where welding and pressing has predominated, has undoubtedly made its impression on the working public as well as on the designers.

Foundry Merchandising

The fact that casting manufacturers have done an outstanding job during this war is recognized and, we believe, understood. Some of the things being done with castings today were unbelievable a few years ago. However, on the matter of merchandising its products, the foundry industry, as a whole, is so far behind that it is not even funny. During this war, the foundry industry needed to give little attention to the matter of seeking buyers. The buyers, it seemed, sought the foundries.

That may be one reason why casting manufacturers have been so reluctant to really sell and produce on anything like the plane that other industries have. The author is convinced that an industry which has shown the progress and accomplishment in methods of production, both scientific and technical, that the foundry industry has achieved, can, if it will, do an outstanding job of merchandising its product.

Industry Cooperation

Whether or not this is possible cooperatively throughout the entire foundry industry, we are not prepared to say. Experience seems to indicate that it has been impossible.

This paper was secured as part of the Program for the 1945 "Year-Round Foundry Congress" and is sponsored by the Inspection of Castings Committee of A.F.A.

If such is the case and it is impossible, then let the various branches start at once toward the desired goal by doing the job individually but to the point of refraining from casting aspersions within the foundry camp.

There is too much to be done, if we are to catch up with welding, stampings, and other competitive constructions, to waste energy by swinging on one another within our own industry.

Future Planning

Until just recently, it was considered rather unpatriotic to think of planning for the future. Our job, as manufacturers, was definitely indicated to us to keep producing everything necessary to speed the day when the United Nations could successfully conclude this war. We were persuaded to forget future planning and thinking. Recently, however, there has come a change in this direction. It is now once again respectable for manufacturers to engage in the necessary practice of planning for the future.

It is interesting to note, in passing, that politicians, social reformers, farmers, labor unions, and other groups have been planning plenty all during this war effort, and are continuing to do so today. Consider this thought: if the foundry industry does not do some planning of its own and have some things ready to present for itself, it may find that others have undertaken to do the job for it.

The specific problems which, to the author's mind, concern the foundry industry today are the selfsame problems which have confront it in the past. Either we solve these problems or we disintegrate. Each one of these problems could be answered by intelligent and cooperative effort on the part of the entire industry by doing a more constructive job with recognition of certain outstanding needs and in the determination of these needs through joint action.

Successful Foundry Organized

It is very simple to see that whereever we find a successful foundry, we find an organization which has done two things: improved its product to the highest degree possible and then set out to do a really constructive merchandising job. The lesson is obvious. It is possible to stimulate demand by making known the desirable features in a product. And it is possible to gain a position of national leadership through concerted, unified action.

The story of what American industry has done through cooperative action during this war is one of the most fascinating, as well as satisfying, pages in the industrial history of our country.

Converting peace time factories and organizations into arsenals of war shows the initiative and ability of American engineering minds. Our success on land, sea and air has been due to a cooperative spirit between all industries. One thought in everyone's mind being to win the war first.

Some Aspects of
GREEN DEFORMATION and SAND TOUGHNESS
In Sand Control

By Wm. G. Parker,
Metallurgical Dept., Elmira Foundry Co.,
Elmira, N. Y.

• Deformation and sand toughness number determinations provide the foundryman with important tools — too seldom used — for molding sand mixing efficiency and workability control — these factors directly affecting the amount of foundry scrap and machining time.

SAND control work, like other phases of foundry technology, should consider every advantage if the greatest amount of good is to be derived. It is the general practice among foundrymen who incorporate sand testing in their procedures to check the green compression strength, permeability and moisture. These all have importance in their own right. However, the green deformation test, when properly made and interpreted, can be of equal importance.

Although the deformation test is an important one, it is not used frequently, possibly because it needs special apparatus and involves some extra work. Furthermore, its bearing is not always understood.

It is agreed by foundrymen who have devoted any appreciable time to testing, that this test should be given greater attention in sand control work. Like any other test, the equipment used requires careful thought and manipulation. However, the amount of extra work necessary in setting the deformation attachment is very little. The actual procedure, as used by the author, will be described later in this paper.

Reducing Defects

Deformation is a sand characteristic which will not do the greatest amount of good unless other factors, such as the type of sand, type of bond, condition of preparation, moisture content, etc., are considered. When all these factors are taken into consideration, it becomes an extremely useful and important test and a definite aid in reducing defects in a foundry.

Opinions differ among operators regarding the factors which affect deformation and the interpretation of test results. R. Chadwick[1] states, "Molding sand, like other materials, may possess sand strength but the strength is considerably limited due to a property which might be termed deformation." This writer firmly believes that if foundrymen were not so callous as to believe strength alone to be a deciding factor, much good could be derived by making application and endeavoring to secure correct interpretation.

The writer has long been interested in two properties of sand, namely, deformation and toughness. In his sand testing work, he found quite frequently that, in using the deformation attachment as supplied by the manufacturer, a "following along" with the arm of the machine as the deformation occurred, gave erratic results.

Test Apparatus Modification

To obtain results that check closely, he made certain modifications in the commercial apparatus commonly employed. These are shown in Figs. 1, 2 and 3.

The deformation test is made on the commercial motor-driven, sand strength machine at the same time that the sand specimen is tested for green compression strength. After placing the 2-in. A.F.A. standard specimen between the lower test heads, the deformation arm is lowered, making contact with the weight arm. Load is then applied on pusher arm by starting motor and running only long enough to show 1 psi. compression strength on the green strength scale.

This takes up all slack between

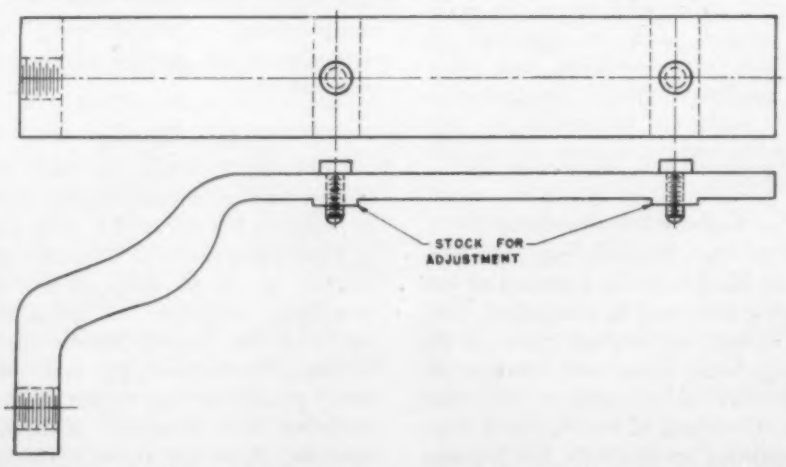


Fig. 1—Bracket used to hold deformation accessory. This bracket is the support which holds the deformation accessory independent of the holding weight shaft. Before drilling and tapping the two threaded holes in the head of the machine, make certain that the alignment or swing of the arm is equidistant throughout the travel on the arc of the machine.

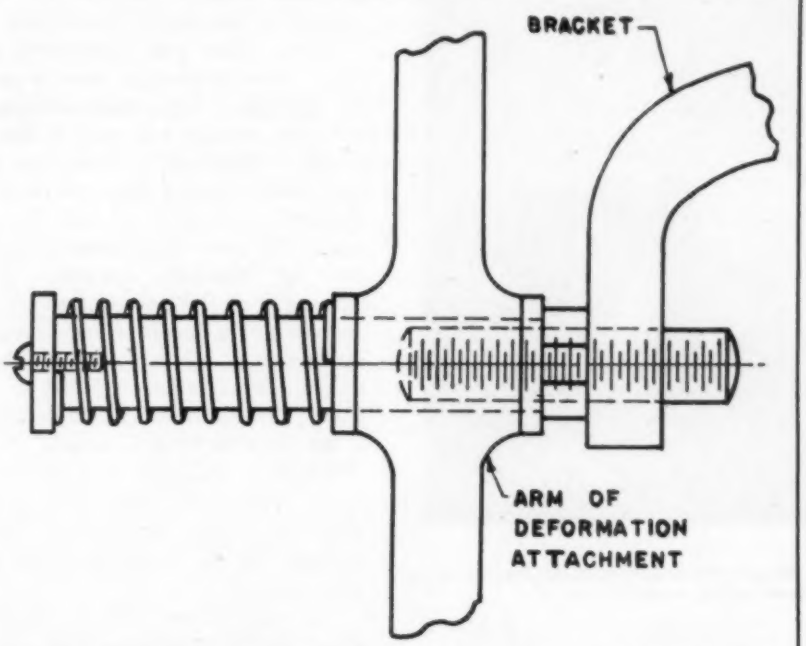


Fig. 2—Detail drawing of bearing for arm of deformation attachment as attached to the bracket shown in Fig. 1.

pusher arm and weight, making good contact between the sand specimen and test heads. At this point, the bezel dial on the deformation indicator is set at zero with the black hand; the red maximum hand is set against the indicator hand. Proper tension on the indicator shows a constant movement on indicator hand throughout deformation of the specimen. Failure of the hand to keep traveling while pressure is exerted, is due to lack of resistance at the indicator where contact is made on the arc of the machine.

To eliminate the parallel travel which the writer experienced in his testing, he made certain modifications in the present test apparatus. A separate bearing (Fig. 2) was attached to the topmost part of the machine, freeing the deformation attachment from the movable arm originally designed for attachment of the deformation accessory. An actual photograph of a machine with this modification is shown in Fig. 4.

Figures 2 and 4 show a brake shoe with an adjustable feature which allows the proper tension to be applied to the assembly to arrest the motion of the arm while performing the test. With these changes in the testing apparatus, we have been able to measure deformation of the sands used in our foundry consistently.

Figures 3 and 5 show the adjustable tension stop located at the end of the deformation accessory which rides on the steel arc of the testing machine immediately above the gear. The author designed this attachment to eliminate the "following along" experienced with the commercial set-up encountered when making the deformation test, and which was responsible for the erratic results obtained.

Deformation is expressed by the author in thousandths of an inch per 2 inches. (The recognized method of expressing deformation is inches per inch.) It is measured by means of the attachment to the compression strength testing machine.

If the deformation obtained on the sand is multiplied by the green compressive strength and the product multiplied by 1000, the figure obtained will express what is known as toughness of the sand, and the number itself is the sand toughness number. This number formerly was referred to as resilience. The late Professor A. C. Davis, Cornell University, called attention to the fact that resilience was an incorrect term and showed that toughness was the correct one.

What Deformation and Toughness Show. There seems to be a prevalent opinion held by those who have given much thought to the matter that deformation indicates the efficiency with which a molding sand has been mixed, that is, mixing efficiency. Many operators who determine deformation do not take the trouble to calculate the sand toughness number. However, in the opinion of the writer, the sand toughness number is an indication of the workability of the sand. Workability might be defined as the ease with which a molding sand can be formed into a mold of the required properties.

Molding Sand Plasticity

Buchanan[2] seems to feel that plasticity, which is necessary in a molding sand, is not in any way measured by the compressive strength test. In the writer's opinion, the deformation of a foundry molding sand determines: (1) the ease with which the pattern may be drawn from a mold and (2) the degree of accuracy of the mold cavity. Should either of these difficulties be encountered, the first obviously slows down production and the second either reduces the number of good castings pro-

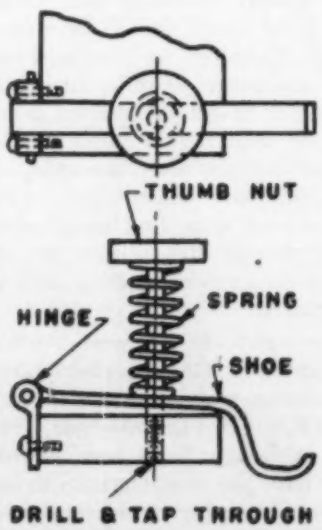


Fig. 3—Adjustable tension stop. This adjustable tension stop is located at the dial end of the deformation accessory and is held as shown. The shoe rides on the steel arc of the machine immediately above the gear.

This paper was secured as part of the 1945 "Year-'Round" Foundry Congress and is sponsored by the Committee on Deformation, Foundry Sand Research Project, Technical Development Program of A.F.A.

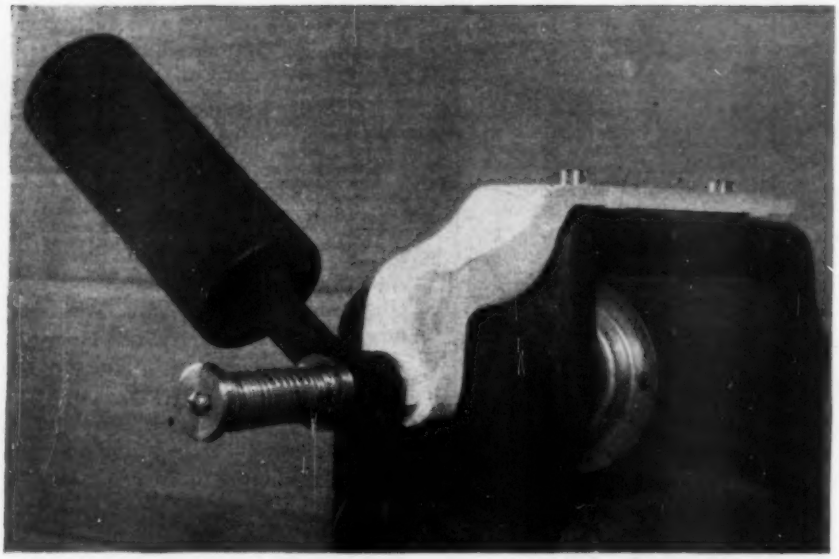


Fig. 4—Illustration showing the installation of the bracket and bearing at the top of a commercial, motor-driven sand testing machine.

duced or increases machining time.

Deformation vs. Green Strength. Deformation does not necessarily change in a constant ratio with green compression strength. Some binding materials give greater green compression strengths than others. This being true, it can be seen readily that, to get the same strength with different bonds, varying quantities must be used, providing everything else is equal.

Deformation and green strength are factors resulting from binding material additions. Some bonds possess greater plasticity than others. We have found this to be true by trials. Therefore, we have used varying percentages of different binding materials to get the desired results.

Two sands might differ in their green compression strengths, yet show the same deformation, or they might have same toughness number even though they varied in both green compression strength and deformation.

Examples. In our work, we have a number of different sand mixtures employing new sands which range in A.F.A. grain fineness from 145 to 45. Although these sand mixtures may have like characteristics in some of the physical tests, one sand would not supplement the other for best usage.

As an example, we mention the two cases shown in Table 1. Case 1 shows that, under *A*, we have sand which has only one-half the deformation value of that shown under *B*. This would indicate insofar as green compression strengths are unlike and moistures are nearly alike, that there must be a difference in sand grain sizes or the actual bond used. Case 1 also shows the same permeability in both *A* and *B*. This eliminates grain size. The most plausible answer would be the amount or the kind of bond used.

Mixing time and equipment all play a very important part in getting full value from bond additions. We may assume that sand *B* shows proper mulling and *A* shows that we have much unused bond still in our mixture. In Case 2, *C* and *D* represent the same sand with a variation of moisture content. This difference of 0.9 per cent moisture gives a green compression strength difference of 1.7 psi. and a difference in deformation of 0.003 in. in 2 in. The sand toughness number is the same in both *C* and *D*.

Effect of Changes in Sand Mixtures. The deformation of a green sand will vary depending upon changes in the ingredients of the sand mixture.

To understand these changes, which the different ingredients might have, it is necessary to understand the reaction of each not only individually but in combination with each other. It has been found that these changes do not give parallel lines on a graph. For this reason, when establishing a synthetic sand, it is necessary to consider grain size and distribution, bonding and glaz-

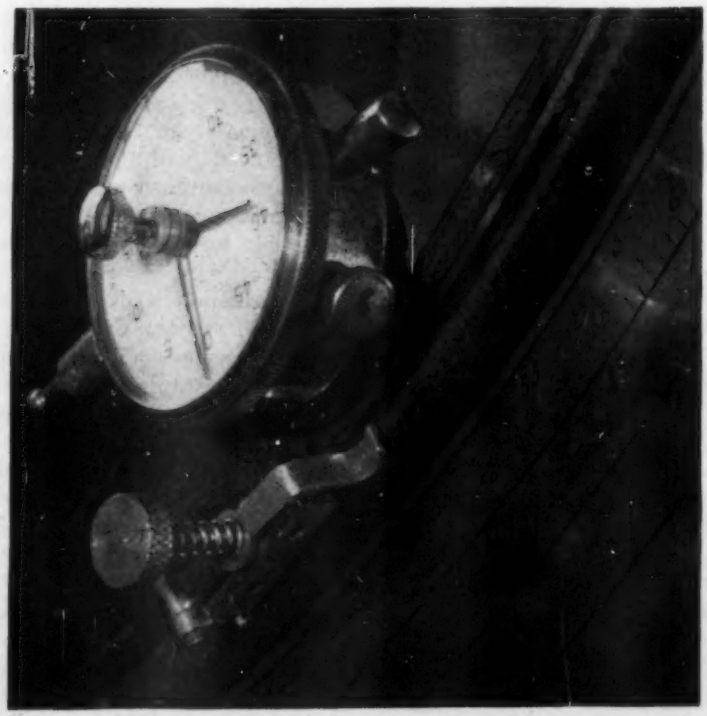


Fig. 5—Illustration showing the adjustable tension stop detailed in Fig. 3 attached to the arc of the machine.

Table 1

SAND PHYSICAL PROPERTIES

Sand	Moisture, per cent	Green Compression Strength, psi.	Green Permeability	Deformation, in. in 2-in.	Sand Toughness Numbers
		CASE 1			
A	4.1	8.1	150	0.015	121
B	4.2	7.3	150	0.030	319
		CASE 2			
C	5.5	9.4	25	0.014	131
D	6.6	7.7	24	0.017	131

ing materials, mulling time and moisture content.

Deformation vs. Sea Coal. There seems to be a difference of opinion as to the effect of sea coal on deformation. Chadwick[1] states that its addition makes the sand-clay mix short and brittle, while the bond strength increases. Dietert[3] states that toughness and deformation increase up to a certain point beyond which both decrease as more coal is added.

Deformation vs. Other Sand Properties. Other properties of a molding sand having definite effects on deformation and their correlation are not discussed here.

Sand Toughness

As previously stated, sand toughness is directly related to deformation. H. W. Dietert and E. E. Woodliff[3] have stated that ". . . resilience (toughness) values are in reality the true working strengths of a molding sand." It has been stated further that the terms "resilience," "workability," and "sand toughness" all express the same sand characteristics. It is the writer's opinion that the sand toughness numbers are the indication of the workability of a sand and that by their use, sand control can be simplified.

Effect of Changes in Sand Mixtures on Toughness. Increasing bond tends to make sand toughness numbers rise. Flowability also decreases, which makes the sand harder to ram and, as a result, requires a longer time to accomplish the ramming work. Likewise, the converse of this is true.

The optimum sand toughness number required in a given foundry will be dependent upon the materials at hand, preparation equipment available and the type of castings made. The leeway between toughness numbers is relatively small. We have found in our foundry operations that it is not necessary to be too cut and dried in considering this tolerance.

As an example, take two sands with a toughness number of 150. One sand may be used in a mold which is to be filled with metal which has a minimum pouring temperature and will result in a good finish on the casting. The other sand, having the same toughness number, may be prepared with less refractory materials, with an inferior bond and be poured with much hotter metal. Such a combination would not stand up to give a satisfactory casting.

Toughness vs. Permeability. With increasing sand toughness numbers, there is usually a decrease in permeability, because more moisture or bond has been added.

It is advantageous to keep the bonding material within safe working limits in using this expedient for control work. There is objection to using bond to increase the over-all sand toughness number. However, additional bond works against the purpose for which it is added, unless the mulling equipment and operat-

SAND CONTROL

DEPT._____ DATE _____

LOCATION	TEST DATA			ADDITIONS		
	S.T.N.	MOIST	COAL	SAND	BOND	COAL

Fig. 7—Form used to show additions to be made to sand, separate floors and facings.

SAND CONTROL

DATE _____ TIME _____

LOCATION _____

MOIST. PERM. STR. DEF. S.T.N. FLO.

Fig. 6—Chart used to report properties of mulled batches to operators.

DAILY SAND CONTROL TEST SHEET

SHOP NO._____ DATE _____

LOCATION	TEST DATA: MOISTURE	PERMEABILITY: GREEN	PERMEABILITY: DRY	STRENGTH: GREEN	STRENGTH: DRY	STRENGTH: TENSILE	COMBUSTIBLES	FLOWABILITY	DEFORMATION	S.T.N.	GRAIN FINENESS		REMARKS	CONSUMPTION: STORAGE	CONSUMPTION: DAY	CONSUMPTION: NIGHT
															BET	
															McC	
															BOND	
															COAL	
															BET	
															McC	
															LYC	
															BOND	
															COAL	
														FACE		

REMARKS

Fig. 8—Chart used to compile complete daily sand testing data. This form is kept on file.

ing procedures are such that no free bond is present after preparation.

Toughness vs. Grain Size. Other things equal, the smaller the grain size, the greater the sand toughness number. It is only necessary to understand that with the finer sands greater areas are exposed, thus making them more vulnerable to the bond material.

Toughness vs. Defects. A chart[4] is available showing relation of the sand toughness numbers to different mixtures as follows:

Ferrous and non-ferrous sands with sea coal.....60-130
Gray iron and malleable sands with sea coal.....70-130
Clay, bentonite, cereal bonded steel green sands.....80-170
Skin or oven dried molds, steel sands 150-230

Above the upper limits of each group, there may be danger of scabs, buckles, or blows; while below the lower limits, there is danger of cutting, drops, rat tails, and mold peeling.

Sand control in any foundry can be expected to produce results, namely, decrease the number of defective castings, improve finish and shakeout conditions which reduce lumping of sand to a minimum, and improve the speed of production and accuracy of the castings, only if proper records are kept and used.

Records are of no value unless they are studied for trends, with the idea in mind of avoiding difficulties before they happen and by correlating them with conditions that obtain in the foundry. The company with which the author is associated believes also that there is a certain psychological advantage in the use of records from the sand preparation point to the final testing. As a result, it has devised the test sheets shown in Figs. 6, 7 and 8.

Figure 6 shows the form used to report the properties of the sand to mixer operators on mechanical sand systems. Figure 7 shows the form used to show the necessary additions to be made to sand on separate floors and those required for facings. Figure 8 shows the complete record sheet which is kept on file for future reference and records all test data for a given day.

It should be noted that on all sheets, sand toughness number (S.T.N.) is required and given, and that on the forms shown in Figs. 6 and 8, deformation also must be recorded. These facts indicate the belief of the author's company in the usefulness of deformation and sand toughness data.

The writer believes that every defect relative to casting finish hinges on a better understanding of sand toughness and deformation qualities. Sand toughness numbers can be the short-cut in sand control where plasticity and green compression strength are considered. Through the use of these numbers, once established, the true significance of control can be greatly simplified.

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Heat Treatment Study of

Pearlitic Malleable Cast Iron

By R. W. Lindsay, Assistant Professor of Metallurgy,
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• ***An investigation of certain phases of the heat treatment of pearlitic malleable cast iron—an attempt to show a correlation between the microstructures and hardness values obtained. Heat treatments—oil quenching followed by tempering, and isothermal transformation at various subcritical temperatures. Concluding that pearlitic malleable cast iron responds to heat treatments similarly to steel.***

ONE of the present interesting cast materials is so-called pearlitic malleable cast iron. This group of irons combine some of the more advantageous features of gray cast iron, particularly resistance to certain types of wear, with a definite ductility which is lacking in the latter. Various details of the processing of such irons have been described in the ASTM *Symposium on Pearlitic Malleable Cast Iron.*[1]

Briefly, the starting point in manufacture is white cast iron of an analysis as will be indicated later. The structure of this raw material consists of pearlite and excess carbide, and by suitable heat treatment this is converted into a structure consisting essentially of lamellar or spheroidized pearlite plus graphite, the latter being in nodular or temper carbon form.

There are two possible methods of accomplishing this structural conversion:

1. By arresting the first stage of the malleablizing process above the A_1 temperature at the point where the excess iron carbide has been converted into temper carbon, and then by subsequent manipulation producing the desired decomposition product of austenite, or less commonly;

2. By complete malleableization to a structure of ferrite and temper carbon followed by reheating to such temperatures above A_1 that the austenite is caused to redissolve carbon and again produce the desired matrix by suitable regulation of the decomposition of austenite.

Admittedly there are various modifications of the possible methods described, and for a description of such, as well as details regarding temperatures, times and process, attention is directed to the aforementioned symposium.[1]

Since the structure of this material after malleableizing treatment consists of pearlite and nodular graphite, it is possible by heating to proper temperatures to convert this to a structure of austenite and nodular graphite.

By suitable regulation of the subsequent cooling rate and cooling conditions of this latter structure, it is possible to produce any of the transformation products of austenite, including the acicular products known as bainites, which have received much attention in the heat treatment of steel in recent years.

This investigation deals with two phases of the heat treatment of a typical pearlitic malleable iron. In one case the samples were subjected to a more or less common heat treatment consisting of oil quenching followed by tempering at various subcritical temperatures for various lengths of time.

The other heat treatment consisted of quenching samples to various subcritical temperatures below A_1 and holding at temperature to study the time of transformation of austenite and the hardness of the transformation product at various temperatures.

Such heat treatment has been termed isothermal transformation (transformation at constant temperature). Microscopic examinations were made of the structures developed as a consequence of such isothermal transformations.

Both of these heat treatments were in the nature of preliminary studies for possible future work involving

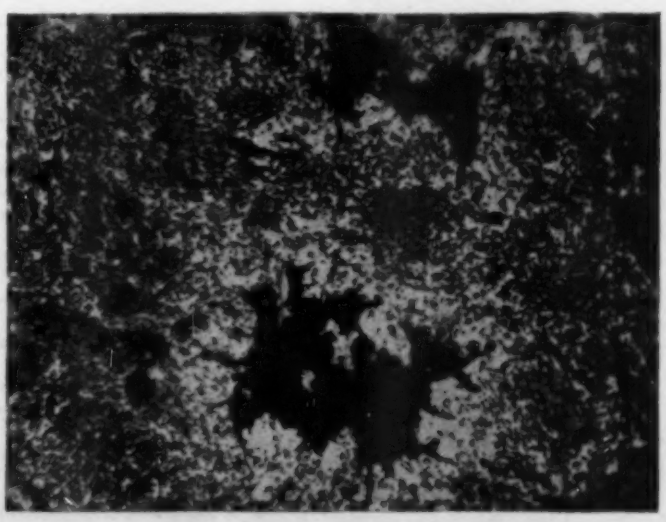

Fig. 1—Microstructure of the iron as received from manufacturer. Nital etch. 500X.

a comparison on pearlitic malleable iron of properties of quenched and tempered specimens with properties of isothermally transformed specimens of the same hardness.

Review of Literature

The investigations regarding the various phases of the heat treatment of steel have become so numerous that one can keep abreast of the developing and expanding picture best through the medium of the publications of various technical societies.

In recent years, similar attention has been fixed upon gray cast iron. Studies similar to those presented in this paper have been reported by Cohen and Hilliker,[2] Dowdell and Nagler,[3] Murphy and Wood,[4] and Flinn, Cohen and Chipman.[5] A summary of these and other investigations upon the subject of the heat treatment of gray cast iron has been presented by Hafsten.[6] Bartholomew[7] has described a practical application of isothermal transformation heat treatment to alloyed gray cast iron machine parts.

With specific reference to pearlitic malleable, Joseph[8] has discussed some of the phases of the heat treatment of this material in his many contributions to the subject. Cowan[9] has broached the subject of isothermal transformation heat treatment of pearlitic malleable cast iron and has presented photomicrographs of some of the transformation products.

In an interesting discussion of Cowan's paper, Walker[10] has suggested the use of isothermal transformation heat treatment as a means of accelerating spheroidization of pearlitic malleable, and has shown some results of such a heat treatment in the form of photomicrographs and a so-called "S" curve.

Experimental Technique

The material used for this investigation was received from the manufacturer in the form of tensile bars. The following analysis may be taken as typical of this iron:

Element	*Per Cent*
Carbon	2.55-2.65
Silicon	1.30-1.45
Manganese	0.42-0.47
Sulphur	0.11
Phosphorus	0.055

The microstructure in the iron as received and prior to any heat treatment by the authors is shown in Fig. 1.

Samples used for the heat treatment studies were cut from the tensile bars. All samples were cut to approximately the same thickness, namely, 0.15 in. The pieces used for the quench and temper runs were taken from the shoulders of the bars, and hence were ¾-in. diameter, while those used for the isothermal transformation runs were taken from the gage length portions where the diameter was ½ in.

Preliminary trials indicated that

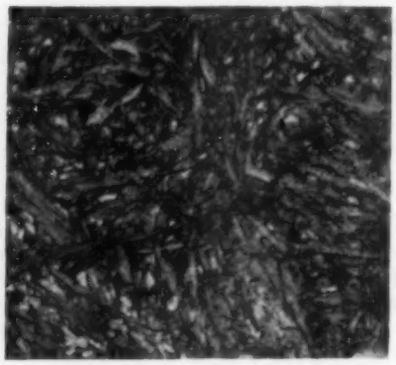

Fig. 2—Martensitic structure in the iron resulting from an oil quench. Nital etch. 1000X.

the structure of austenite (plus nodular graphite), which is, of course, necessary for structural manipulation by subsequent adjustment of cooling rates and conditions, could be produced by holding the samples at a temperature of 1600° F. for 30 min. Consequently, this treatment constituted the first step in either of the two types of heat treatment.

Such heating was conducted in an open muffle electric furnace equipped with automatic temperature control. Precautions were taken to keep the samples off the floor of the muffle and to have the hot junction of the controlling thermocouple in close proximity to the samples. In all instances, the samples were introduced into the hot furnace already controlling at 1600° F.

Quench and Temper Treatment—All samples subjected to various tempering treatments were first quenched in oil from 1600° F. to ordinary or room temperature. Groups of such oil-quenched samples were then tempered at various temperatures, namely, 650, 750, 900, 1000, 1100 and 1200° F. A different group of samples was employed for each tempering temperature. The tempering times at each temperature were 15, 30, 45, 60, 120 and 240 minutes.

Tempering of the quenched samples was conducted in a bath of molten lead maintained at the desired temperature in each instance.

Isothermal Transformation Heat Treatment—The essence of this particular heat treatment is to cause austenite to decompose directly at various subcritical temperatures (i.e., temperatures below A_1 in the iron-carbon diagram) to transformation products characteristic of these temperatures.

Therefore, to accomplish this it is necessary that the sample be cooled from the austenitizing temperature to the subcritical temperature in question at such a rate that austenite will be the sole matrix constituent present originally in each and every sample brought to that particular subcritical temperature for study. Thus, it will be the decomposition

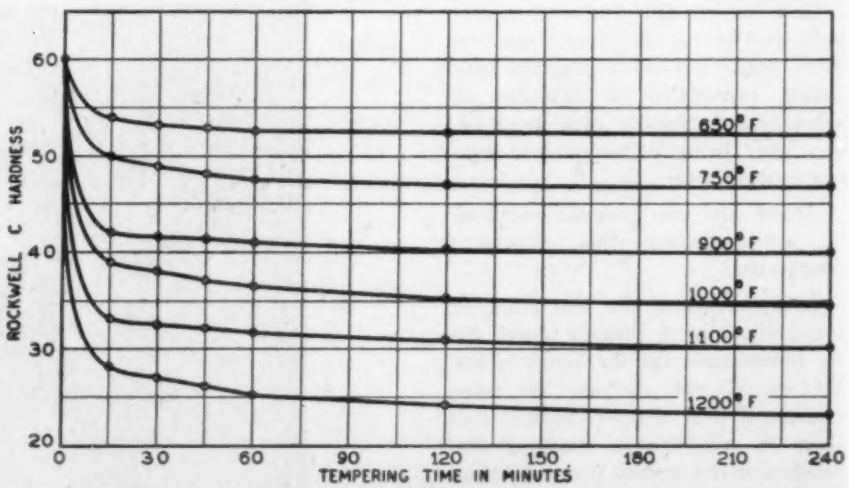

Fig. 3—Relationship of Rockwell C hardness to tempering time for each tempering temperature studied.

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of austenite at temperature which will be subjected to investigation.

Such requisites can be satisfied, as was done here by using relatively thin samples quenched from the austenitizing temperature into a bath of molten lead set to control at a specific temperature. In this way, the austenitic condition could be undercooled (below A_1) to certain temperatures by varying the temperature of the lead bath, and its transformation could be studied at these various temperatures.

Isothermal transformations were followed in this investigation at temperatures of 1200, 1100, 1000, 900 and 750° F. by the method to be described in a subsequent section.

Quenching and Tempering Runs —The results of this part of the study are much as would be expected. The samples as quenched in oil from 1600° F. possessed the matrix structure of martensite shown in Fig. 2. The hardness of such a structure was consistently Rockwell C 60 (±1).

This martensitic structure and hardness is representative of the original condition of all oil-quenched samples subjected to tempering. The behavior of these quenched samples upon tempering at various temperatures is shown in the form of curves relating Rockwell C hardness to time of tempering in Fig. 3.

It is apparent that at each temperature the hardness of the quenched structure decreased rapidly in the first 15 min. and this was followed by further, more gradual softening over the remainder of the tempering period.

The well-known fact may also be noted from Fig. 3 that, the period of tempering being constant, the products of tempering are softer as tempering temperature is increased. This is more readily apparent from Fig. 4, wherein the decrease of hardness with increase of tempering temperature is plotted for a constant tempering period of one hour at each temperature.

This plot is approximately a straight line relationship over this range of temperature, namely, between 650 and 1200° F. This change in hardness correlates with changes in microstructure, as shown in Fig. 5. It can be noted that there is a progressive coalescence of the carbide with increase of tempering temperature up to the point where the specimen tempered at 1200° F. shows a rather definite spheroidized structure.

Isothermal Transformation Runs —The method used to follow the progress of the decomposition of austenite at various subcritical temperatures was the microscopic method originally suggested by Bain and Davenport.[11] The necessary technique for bringing structures of austenite (plus nodular graphite) to the subcritical temperature in question was described earlier in the paper.

Briefly, the microscopic method is conducted as follows: A batch of thin specimens is quenched from 1600° F., in this case, into the lead bath controlling at the desired

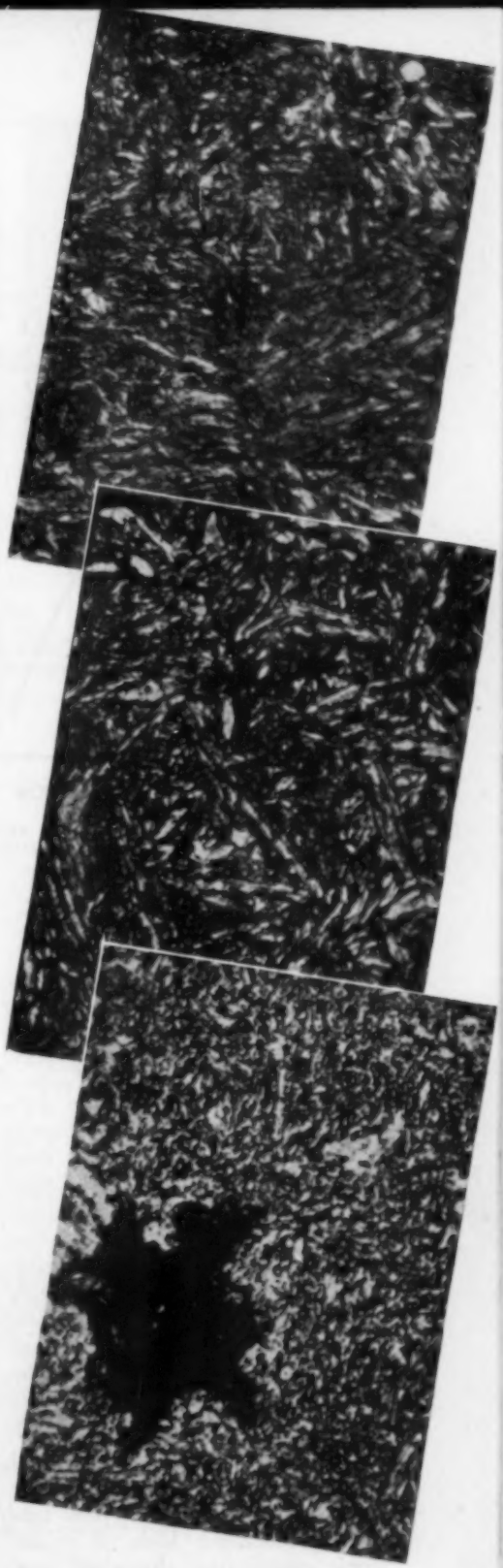


Fig. 5—Photomicrographs showing the structures produced by tempering oil-quenched samples for 1-hr. periods at temperatures (top) 750° F., (center) 1000° F., and (bottom) 1200° F. All 1000X.

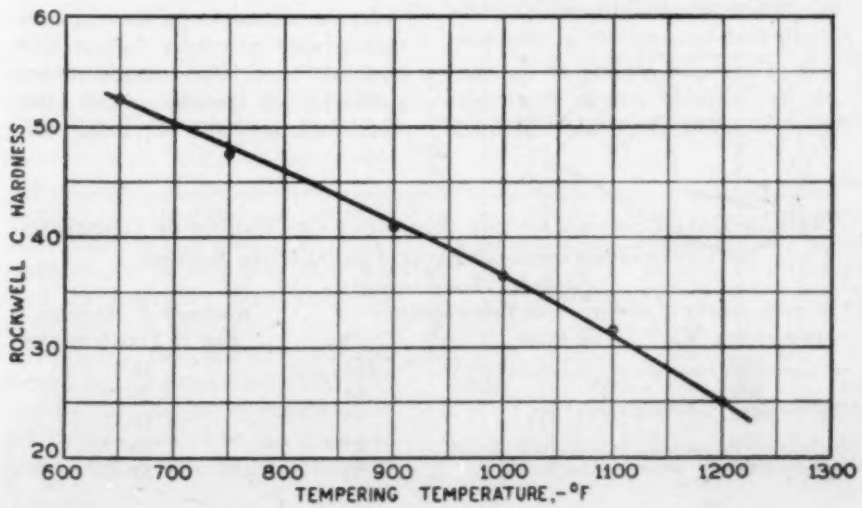


Fig. 4 (Left)—Progressive decrease of Rockwell C hardness with increase of tempering temperature. Samples were tempered for one hour in each instance.

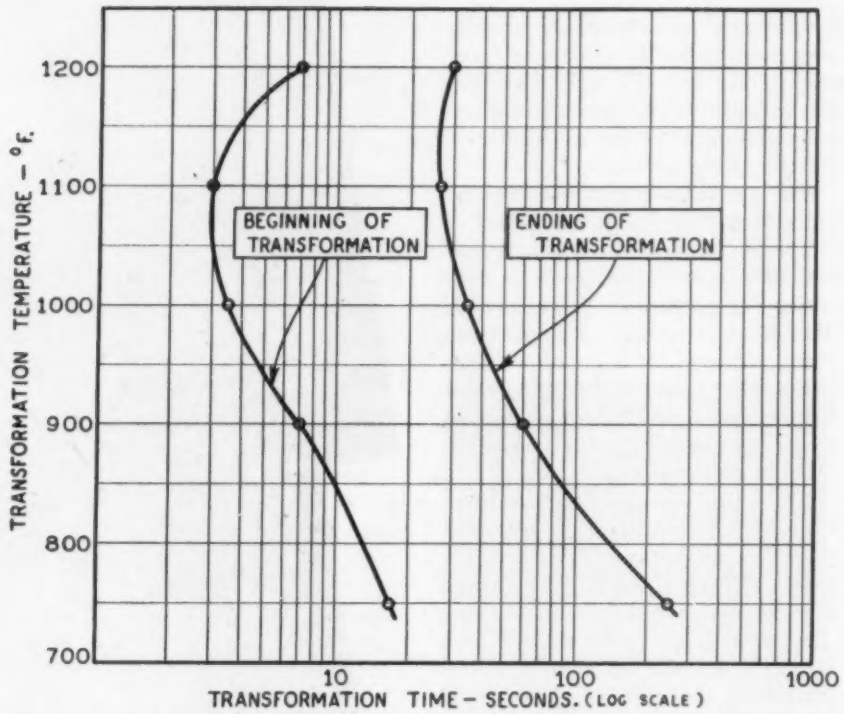


Fig. 6—Semi-logarithmic plot showing approximate beginning and ending of isothermal transformation at various subcritical temperatures.

temperature. Following a preselected time interval, one of the samples is removed from the bath and immediately quenched to the ordinary temperature in water. The sample is then examined microscopically.

It is known that austenite does not transform to martensite except at relatively low temperature (here in the water quench), and hence any martensite found in the microstructure will represent areas that were austenitic prior to the water quench or at the time the sample was removed from the subcritical lead bath. On the other hand, any product of transformation of austenite, such as pearlite or bainite, will be unaffected by the water quench.

This transformation product was present at the time the sample was removed from the lead bath and water quenched. Thus, if microscopic examination shows the sample to be 100 per cent martensite after water quenching from the lead bath, this means that the structure was 100 per cent austenitic at the time of removal of the sample from the lead bath. In other words, at that subcritical temperature (the temperature of the lead bath) the transformation of austenite had not commenced by the time the sample was removed and water quenched.

Any percentage of martensite less than 100 per cent in the microstructure would indicate the transformation of austenite in the lead bath to a lesser or greater degree. The amount of transformation can be estimated from the relative proportions of martensite and transformation product in the microstructure.

It is obvious that the requisites of this method, or any method, for studying the subcritical decomposition of austenite are:

1. The use of thin samples which are rapidly transferred from the austenitizing temperature to the subcritical temperature to insure that the sample as it initially comes to the latter temperature will rapidly attain that temperature as austenite.

2. The rapid cooling of the sample to ordinary temperatures once it is removed from the subcritical temperature being explored, so that the condition of the sample upon removal from this subcritical temperature is retained as much as possible (excepting, of course, that change from austenite to martensite in the water quench cannot be avoided).

Samples were quenched from 1600° F. to each of the subcritical transformation temperatures studied to determine the approximate beginning and ending of transformation at each temperature. In each instance, preliminary exploration was made at any temperature by quenching a group of samples into the lead bath and removing individual samples after 1, 5, 10, 100 and 1,000 seconds.

Additional samples were then quenched to and held at these temperatures in order to determine the beginning and ending times as was indicated to be necessary from the preliminary group.

The results of this stage of the investigation are summed up in Fig. 6 and the table. The time for the approximate beginning and ending of transformation at each temperature has been plotted (Fig. 6) in semi-logarithmic fashion and the results presented also in tabular fashion.

Transformation Products

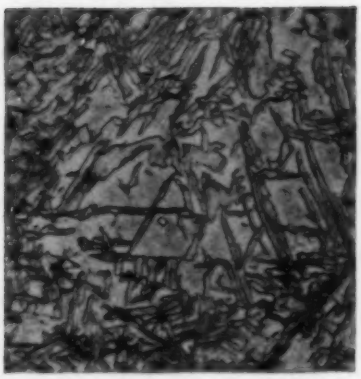
The behavior of pearlitic malleable iron in these isothermal transformation heat treatments is further portrayed by the use of photomicrographs. These are presented in Fig. 7. One photomicrograph of the transformation product typical of each temperature is given, and it is to be noted that in each case a partially transformed sample was selected to better illustrate the nature of the product.

A consideration of these photomicrographs will show that at 1200 and 1100° F. the transformation product was pearlite, with that developed at 1200° F. being defi-

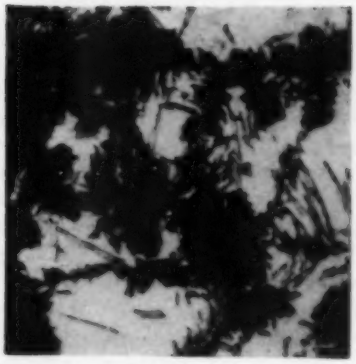
TABULAR DATA CONCERNING THE BEGINNING AND ENDING OF ISOTHERMAL TRANSFORMATION AT EACH TEMPERATURE STUDIED

Transformation Temperature °F.	*Approx. Time (Seconds) for Transformation To Begin*	*To End*	*Rockwell C Hardness at End of Transformation*
750	17	250	36-37
900	7	60	29-29
1000	3½	35	38-42
1100	3	27	35-37
1200	7	30	32-32

750° F.—100 sec.

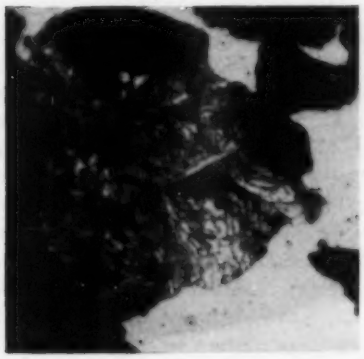


900° F.—30 sec.



1000° F.—10 sec.

1100° F.—10 sec.



1200° F.—15 sec.

Fig. 7 — Photomicrographs illustrating the various structures developed by isothermal transformation at the indicated subcritical temperatures. Samples only partially transformed. All 1000X.

nitely more lamellar in appearance than that at 1100° F.

The structures developed at 900 and 750° F. are acicular or needle-like in appearance, the needles in the 900° F. sample appearing whitish and more coarse than those in the 750° F. sample, which etched dark. The sample transformed at 1000° F. appears to consist principally of dark etching nodular pearlite, but a few traces of acicular product are evident.

An interesting feature is evident when the hardnesses of the samples which were approximately completely transformed are plotted against transformation temperature, as in Fig. 8. It is apparent that as transformation temperature is decreased from 1200 to 1000° F., the hardness of the nodular pearlitic transformation product increased progressively, as might be expected from the increasing fineness of the transformation product.

However, the acicular product formed by transformation at 900° F. was definitely softer, as indicated by the dip in the curve at this temperature. Further lowering of transformation temperature to 750° F. caused the acicular product to become definitely harder again, comparable with the hardness of the pearlitic transformation at 1100 or 1000° F.

Similar behavior has been found in the isothermal transformations of gray cast iron by Murphy and Wood,[4] as well as Hilliker and Cohen.[2] The latter investigators, by use of special etchants and x-ray analysis, attributed this hardness dip in the vicinity of 900° F. to the fact that the needles were ferritic in nature.

The increased hardness of the acicular structure formed at still lower temperatures was attributed to precipitation of a fine dispersion of carbide in the ferrite needles, which then etch darkly. This is to some extent confirmed by the etching reaction of the acicular structures in Fig. 7, although the present authors made no attempt to further investigate this point.

In summary, the following points are enumerated:

1. At a given temperature of tempering, the hardness of a quenched, martensitic structure will decrease rapidly in the initial stages of tempering to be followed by a more gradual decrease as tempering time is lengthened.

2. Increase in temperature employing a constant period of tempering results in a decrease of hardness

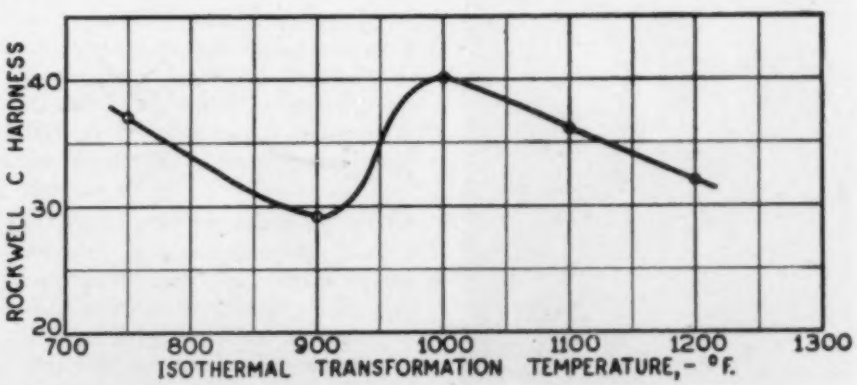


Fig. 8—Variation of hardness of products of isothermal transformation at various subcritical temperatures. Hardnesses taken on samples completely transformed.

in almost linear fashion. This is related to increasing coalescence of the carbide particles in the tempered structure with increase of temperature.

3. Isothermal transformation at temperatures from 1200° F. down to 1000° F. results in a nodular type of pearlite, which increases in fineness as transformation temperature decreases.

4. Isothermal transformation below 1000° F. produces acicular products which have been commonly referred to as bainites. The acicular product formed at 900° F. is softer than the nodular product formed at 1000° F. The hardness of these acicular products increased as transformation temperature was decreased to 750° F.

5. Data obtained as to the beginning and ending of transformation at the subcritical temperatures investigated indicate that transformation is initiated most rapidly at temperatures in the vicinity of 1000 to 1100° F. The time for beginning of transformation was between 2 and 5 seconds, and the transformation product was mainly nodular pearlite.

As a consequence of the present study, some interesting possibilities present themselves for further investigation. It is suggested that a comparison might be made of the properties of pearlitic malleable cast iron after isothermal transformation at various subcritical temperatures.

One important phase of such a comparison would be to determine, first of all, the maximum size of section which could be successfully transformed isothermally. A further extension would be to compare the properties of quenched and tempered structures with isothermally transformed structures of approximately the same hardness.

Such investigations might lead to the development of rather unexpected properties and further applications of this material, as has proved to be the case in steel in certain instances.

Acknowledgment

This is to acknowledge that this work was conducted at the Pennsylvania State College as a senior metallurgical thesis by J. E. Atherton, Jr., under the guidance and advice of R. W. Lindsay, then Assistant Professor of Metallurgy.

The authors extend their thanks to Carl F. Joseph, Research Metallurgist, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich., for supplying the iron used in this investigation.

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STEEL CASTINGS

Repair Methods

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● ***Factors of casting service—character of the defect, as determined by the various test methods available—metal composition—must be considered in selecting a method of defect removal. After suitable examination to assure complete removal of the defect, it must be decided whether repair is necessary or desirable, and if so, the method to be employed.***

AN understanding of the definition of the term "defect" should be a fundamental prerequisite required of all those who shall attempt to condition castings. A defect may be defined as the lack or absence of something essential or, in the foundry, as a discontinuity of metal that may have a harmful influence on the service of the casting. This discontinuity of metal may be due to cavities caused by gas or shrinkage; to included metallics such as chills and chaplets; to non-metallics such as sand and inclusions; to hot tears and cracks; or to combinations of these defects.

It follows that these discontinuities may not be defects unless their presence can be said to have a harmful influence on the service of the casting. The determination as to whether or not a certain type of discontinuity is a defect does not fall within the scope of this paper.

Determination Factors

It should be mentioned, however, that many factors must be taken into account in this determination. Among these factors are the intended service of the casting and the direction and magnitude of the discontinuities in relation to the stresses involved during the service of the casting.

Having determined that a certain discontinuity is a defect, it is then presumed that its location in respect to the depth below the surface and its size have been determined or estimated by visual inspection, cold acid etching, magnetic particle inspection, radiography, drilling, or by other test methods. With this information available and knowing the analysis of the casting, it becomes possible to consider the means of removing the defect. There are three principal methods for the removal of defects: chipping, grinding, and flame gouging.

It is a fact that hardly two foundries will use a similar procedure for the removal of a similar defect, but most foundries will use these three methods to various extents. In general, the small alloy steel foundries tend toward grinding; the large carbon steel foundries toward flame gouging. The three methods and the advantages and disadvantages of each will be discussed separately.

Removal Methods

Chipping. The oldest, and probably still the most generally used, method of removing defects is by chipping. It is usually accomplished by hand with a pneumatic hammer (Fig. 1), using either flat or gouge tools, depending upon the type of defect. The principle advantage of this method is in the removal of small defects. Small cracks and patches of surface sand and shrinkage may be rapidly removed.

The principal disadvantage of this method is the increase in time required to remove large quantities of metal. Another disadvantage is sometimes present, particularly in the smaller castings, when the defect to be removed is inaccessible for proper use of the chipping hammer.

Cracks may be followed by this method, provided that the crack is sufficiently near the center of the chip to cause it to split. Likewise, a crack may be closed by improper chipping so that its presence is difficult to determine unless the excavation is subjected to a magnetic particle inspection or ground smooth in preparation for other methods of inspection.

Due to the foregoing it is usually required that all excavations be checked by some method to assure complete removal of the defect. Grinding is desirable if the excavation is to be checked visually by etching or by radiographing. If the magnetic particle inspection is used, a normally prepared area is gener-

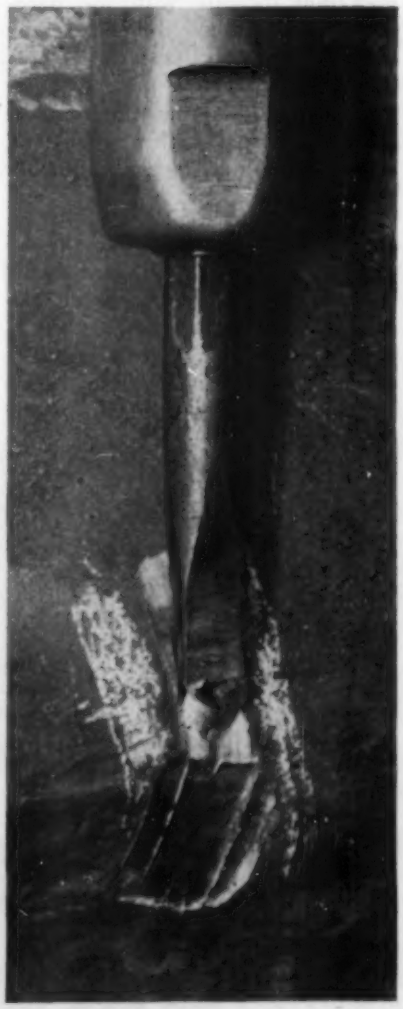

Fig. 1—Removal of casting defect by use of chipping hammer.

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Fig. 2—Preheating casting with gas torch.

ally satisfactory provided, of course, that the type of surface is satisfactory for later repair by welding.

The difficulties of the chipping operation increase with the hardness and toughness. For this reason it is desirable that castings be heat treated by annealing prior to chipping. It follows that the removal of defects from high carbon and alloy castings may be quite difficult.

Factors in Grinding

Grinding. The removal of defects by grinding is used principally on high carbon and alloy steel castings where chipping is not practicable due to hardness or toughness, and in other castings where defects are small and access difficult by the other methods of removal. This method is not used for large defects, unless the analysis of the casting prevents the use of one of the other methods.

Its advantage lies principally with the surface finish that it produces. This surface may be readily checked by any mechanical method of inspection. The disadvantage lies in the fact that it is the slowest method for the removal of defects, and that it is difficult to visually follow the defect during its removal. The possibility of grinding checks in hard materials may also be termed as a disadvantage, as these checks may not be readily visible except by magnetic particle inspection.

Preheating. Preheating is required both b e f o r e flame gouging and welding of castings containing over 0.35 per cent of carbon, and for most alloy grades. Its use is also desirable in lower carbon grades to prevent the formation of cracks if shop or part temperatures are below normal, if manganese and sulphur analysis are abnormal, or if repairs are to be made of large or intricate areas, particularly if the section is of over ¾-in. thickness.

The degree of preheat needed will be approximately the same both for flame gouging or welding. As there are numerous tables published with recommended preheating temperatures required for welding and a few for flame gouging, it is not felt that detailed instructions on this subject are necessary in this paper. Generally, a preheating temperature of 300° F. is required, which is maintained during welding and is followed by slow cooling.

Stress Relief

The purpose of preheating is to eliminate the possibility of cracking, and as the theory applies equally to flame gouging and welding its discussion is felt desirable. In theory, the surface of metal immediately adjacent to the cutting torch or weld metal is first heated to a very high temperature. As the underlying metal is at lower temperatures, it resists the same degree of expansion, resulting in the surface being upset.

Subsequent cooling results in failure due to the inability of the surface to withstand the high stresses involved when the underlying metal resists this contraction. This is particularly true with metals having low ductility, as the more ductile materials will elongate within themselves to relieve or distribute the stresses occurring.

Preheating may be accomplished by a number of different means, among which are preheating in furnaces, either permanent or temporary, by heating torches of gas or oil (Fig. 2), or by electric strip heaters. The latter method is becoming more popular, as heat may be controlled in its location and amount, the procedure gives no objectionable fumes, leaves no residue, and reduces the fire hazard of open torches. It is particularly desirable when large and complicated castings are involved, or when a casting is located within a final assembly.

Flame Gouging. This is one of the most controversial subjects in the foundry. It is the most rapid method for the removal of defects, being variously estimated as being up to ten times as fast as chipping (Figs. 3 and 4). It is claimed that this rapid removal of cracks tends to drive them into the casting.

Theory of Gouging

Theoretically, while the gouging flame is impinging on the casting the surface metal is being heated and expanded, but the adjacent colder metal is resisting this expansion. Therefore, the crack is not apt to progress in heating. Upon cooling, however, it is subject to tensile stresses, and it is at this time that the crack will extend if it still exists, or will originate if metal weaknesses exist within the stressed area.

It is, therefore, important that defects, which may act to increase the existing stresses, be entirely removed before the metal is allowed to cool. Apparently, no satisfactory method of proving whether or not these theoretical conditions are true is available. It is for this reason that this method will probably continue to be controversial.

Although any cutting torch may be used for the removal of defects, certain tips have been developed for this type of work. These tips allow broad and smooth excavations which do not require further chipping or grinding for welding. The tip will depend upon the type of

gas used. Oxyacetylene gas is usually selected, but even city gas may be used, provided that oxygen is present for oxidizing the metal, this being the essential part of the gouging operation.

For the flame gouging of steel castings of up to 0.35 per cent carbon, preheating generally is not required. For castings with carbon contents above this amount, and for alloy castings, it may be necessary to preheat.

The advantage of flame gouging lies entirely in the speed of the operation. It is also the author's opinion that with experience it is the easiest method of following defects to assure complete removal. The fact that this experience is required is the chief disadvantage of the method.

Selection of Operators

Inexperienced operators may cause removal of considerable excess metal due to the speed of this operation or, due to their inexperience, they may not remove sufficient metal to eliminate the defect. In the latter case the defect may be extended further into the casting and require an additional burning operation for its removal. Either of these errors may so increase the cost of repair that the advantages of flame gouging are entirely lost.

If the gouging operation is properly conducted the resulting excavation is satisfactory for any method of checking, including visual inspection. The weld may be deposited on this surface satisfactorily.

Carbon-Arc. Another method of removing defects is by the use of the carbon-arc. This method is considered a variation of flame gouging, and is not generally used but confined to special cases. It differs from flame gouging in that the metal is removed by melting rather than by oxidation. Its chief advantage therefore lies in the removal of defects from high alloys that are difficult to oxidize. Generally, the high alloys of this type do not require preheating.

This method is not recommended for the removal of defects from castings on which flame gouging may be used, as the latter method will furnish a satisfactory and much cleaner excavation more rapidly and with less possibility of further extension of the defect.

The Excavation. With the removal of the defect, two conditions are required of the excavation; (1) that the defect is entirely removed, and (2) that it is weldable.

The soundness of the excavation is commonly assured by visual examination, cold acid etching, or magnetic particle inspection (Fig. 5). Other methods such as the whiting test and the fluorescent tests may be used, but are not generally employed.

The chief disadvantages of the visual examination for assuring soundness is the ease with which tight cracks may be overlooked, particularly on chipped or ground surfaces which may tend to close the defect.

Cold acid etching, as practiced with a 5 per cent nitric acid solution in alcohol and an alcohol wash, will reveal defects principally by the seepage of a dark green solution from the defect to the clean, steel-gray surface resulting from the alcohol wash. The principal disadvantage is that for very tight cracks the etching should be continued for one-half hour. However, for shrinkage and blowholes this method is particularly adaptable due to the speed with which the seepage from this type of defect will occur.

Magnetic Particle Inspection

Magnetic particle inspection of excavations is now generally recognized as the outstanding method for assurance of freedom from cracks and directional defects, both surface and sub-surface. It is not particularly satisfactory for blowholes, etc., which do not have directional properties. This inspection may be conducted by using from 400 to 800 amperes D.C. applied through two prods placed 4 to 8 in. apart.

The application of the prods should be made in at least two directions, 90 degrees apart. Dry powder, either red or black, may be used, and this is applied while the current is passing between the prods. In using this method care must be exercised to keep the voltage low and the contacts good, so that arcing may be held to a minimum. Excessive arcing will cause hard spots that may result in serious difficulties due to the development of cracks from these areas. A switch to break the circuit without drawing an arc is recommended.

"All-over" Method

The "all-over" method of magnetic particle inspection, wherein considerably higher amperages are used with the contacts usually at the extremities of the casting, may be employed in the checking of excavations or other intermediate testing.

However, it is not recommended to check excavations unless better penetration or less arcing due to fewer contacts is desired. For initial or final testing, or where the whole casting is to be inspected, it is highly recommended as it offers an ef-

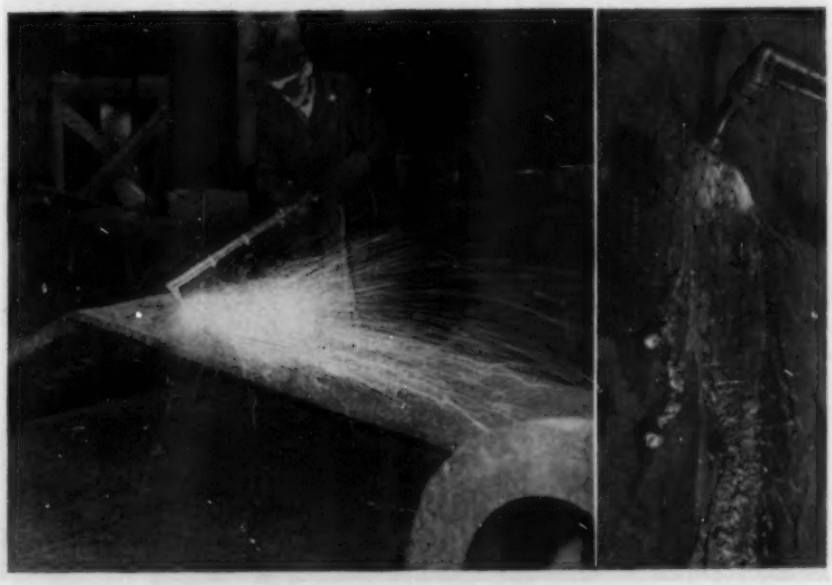

Fig. 3 (left)—Removing casting defect by flame gouging. Fig. 4 (right)—Another view of flame gouging operation.

fective method with great savings in inspection time.

Welding. After the removal of the defect has been assured by a suitable means of examination, it becomes necessary to decide whether welding is necessary or desirable, and if so whether gas, electric or thermit welding should be used (Fig. 6).

It is sometimes entirely unnecessary to weld excavations, due to their size or location within the casting, particularly in machined castings where welding may cause warpage. In fact, in higher carbon and alloy castings which have been machined and cannot be properly stress annealed, it would probably be much wiser to avoid welding if it could be done without affecting the serviceability of the casting.

Stress Development

This statement is made as it is well known that cracks have developed from stresses existing within the hardened area beneath a weld which has not been properly stress annealed. If it is decided to dispense with the welding operation, it must be borne in mind that the excavation must be free of all possible stress concentrations.

This means the removal by grinding of all valleys and ridges developed in chipping, and of all thermal conditions and chemical conditions existing after flame gouging. It is also preferred that the excavation be proved by magnetic particle inspection to verify complete removal of the defect and to assure absence of grinding checks.

If it has been decided that welding repair is necessary, a suitable method of fusion welding must be selected. It is not the purpose to discuss these methods in any great detail, as such a discussion would entail a considerable amount of space.

Welding Methods

The discussion which follows is limited to the general points of interest, as it is felt that all foundries have more or less established welding procedures, but if further information is desired reference to various publications including the *Welding Handbook* should be made.

Gas Welding. This method has in general been superseded by electric or arc welding, although its use may be advantageous in repair welding of small castings. The disadvantage of this method of welding in large castings is the difficulty and expense of maintaining sufficient heat in the vicinity of the weld and the resulting slowness of the operation.

With small castings this disadvantage may be of so little consequence that the better control and manipulation of the gas torch may justify its selection. The oxyacetylene flame is preferred in this type of welding, although the slower oxygen-hydrogen flame may be used under certain conditions.

Electric Welding. Electric or arc welding is the common method by which steel castings are repaired due to the fact that the arc furnishes a suitable source of heat which is effectively concentrated. There are several ways in which this type of welding is applied. These are by alternating or direct current, the latter by either straight or reversed polarity, and by either carbon or metallic electrodes.

Magnetic Blowing

The use of alternating current has as its particular advantage the elimination of magnetic blowing, which is caused by the return of the magnetic circuit in direct current welding, and in the lower cost of both equipment and maintenance. With suitable power available this method of repair welding should increase in popularity. It is particularly adaptable to deep and narrow repairs.

Reversed polarity direct current is now the most popular method of repair welding and is adaptable to all repairs except where magnetic blowing is excessive. The quality of the deposited metal generally excels that of the straight polarity method. Straight polarity is extensively used where specifications allow its use, due to the ease of application.

Carbon-arc welding has in general been replaced by the metallic arc due to the quality of the deposited metal. This method is fast when using large carbon electrodes, and is a very rapid method for depositing metal, but the deposited metal is poor unless shielded, which is the principle of certain automatic processes. These processes are not adaptable to the repair welding of castings.

Electrode Selection

In each case the selection of the type of electrode used will depend upon the method and the material to be welded. Hot electrodes, either by type or size, are to be discouraged in the welding of enclosed cavities, due to increased stresses on restrained areas. The size of the electrode used depends upon the size of the repair or casting. Three-sixteenths and one-quarter in. electrodes are generally used.

Thermit Welding. The use of

Fig. 5—Checking soundness of excavation by magnetic prod method.

thermit welding (Fig. 7) has been more or less confined to assemblies of large or intricate sections or to the repair of broken pieces. In these cases the weld deposit is unrestrained in that one or both ends are free to contract during the cooling cycle. It is not common practice to use this method to repair large excavations in which the deposit is restrained by surrounding metal.

However, it is practicable to use the method provided that the casting is preheated throughout to a high temperature. The preheating temperature is extremely important and the casting should remain red at the welding face for several minutes after removing the preheating torch.

Thermit welding is faster than any other method of welding, and should be particularly advantageous in the repair of the larger excavations. Its disadvantage lies principally in the high preheating temperatures required.

Special Practices. It sometimes becomes necessary to consider means for the excavating and repair of castings other than the usual excavating by flame gouging, chipping or grinding followed by welding. This applies where the defect is of such an extent that excessive removal or extra long welding time is required.

Welding Special Shapes

In these cases the defective area may be cut out in its entirety, and a rolled plate, pipe or castings of equal or higher properties fitted to the area and welded into position by whatever means is applicable. For example, a plate cut to the size required could be inserted and welded, using the electric-arc method, or a section of pipe might be attached by thermit welding. In the case of an intricate shape, a separate casting could be made and welded into position.

In most cases of this type the area to be repaired is cut out and/or beveled by flame machining or cutting. It is desirable, if possible, that this machining be done with a mechanical set-up rather than by hand.

Another specific casting repair is an edge or protruding part of the casting which failed to run, was porous, or otherwise in need of repair. In these cases, if the area is not too extensive, a plate is tack welded to the outside of the casting and the repair built up against this plate. This necessitates the removal of the plate and the completion of the weld by building up the initial deposit.

Fig. 6—Manipulator for casting repair welding.

Many other repair methods exist, but few of these remove the defect. Some of them are recognized as satisfactory under certain conditions; others are not. Among these methods, drilling a defect and inserting either a welded or machined plug is common, as is also the method of closing porosity by sealing compounds either hydrostatically or by surface application.

Shrinkage and Distortion. A major problem in the repair of castings is distortion caused by the shrinkage of the weld in cooling. This problem can be solved, or the condition at least relieved, by the adoption of a suitable welding procedure.

Shrinkage Compensation

Peening or hammering the weld deposit to compensate for the shrinkage is practiced quite generally, but is difficult to control.

Tack welding or jigs may sometimes be employed to prevent distortion, although these methods promote additional residual stresses within the casting.

Residual Stresses. All castings subject to welding repair have residual stresses which, when excessive for any particular section, will cause distortion. The presence of distortion indicates the mechanical relief of stresses which locally may exceed the elastic limit.

Preheating, welding technique, peening, overstressing, etc., may be designed to reduce stresses resulting from repairs, but the complete elimination of stresses is doubtful. This is the reason why stress anneal or heat treatment is felt to be desirable after repairing.

Section Welding

A noteworthy example of welding technique to reduce residual stresses is the procedure for welding a long, narrow and deep excavation. In this case the excavation will be divided into sections and each welded separately. This practice eliminates the high stresses along a long and narrow weld deposit which is not thick enough to withstand them, and substitutes a method wherein a strong weld over-stresses the intermediate voids and assists in the reduction of residual stresses.

Residual stresses are usually estimated, and this estimate is based on the relative depth of the weld deposit to the thickness of the section. In general, ratios of more than one to five indicate the need for further heat treatment.

Heat Treating. The optimum in heat treatment of repaired castings would consist of a preliminary treatment or anneal prior to the removal of the defect, preheating prior to

and during welding, and subjection to final heat treatment after the completion of the repair. This procedure is neither practicable nor economical in many cases, and the usual practice in most foundries is to complete heat treatment before repairing and to follow the repairs with a stress annealing treatment to remove stresses developed in the repairing cycle.

This practice is generally recognized as being satisfactory and is usually specified. Size, shape and analysis of the casting, as well as the type of repair, should be considered in the establishment of the treating cycle.

Stress Annealing. The plastic strength of metal begins to be affected at temperatures above 400° F., and any residual stresses in excess of the maximum strength at that particular temperature will be relieved by the plastic upsetting of the metal.

Fig. 7—Thermit welding of a large casting.

Stress relieving temperatures will depend upon the material and other conditions, but in general the desired temperatures are in the neighborhood of 1100° F. After holding at this temperature for a sufficient length of time, depending upon the section, it will be found that the residual stresses have been practically eliminated. Longer holds at lower temperatures have also been found to be effective, although the higher temperatures are to be preferred.

Cooling from the stress annealing temperature is of particular importance in the case of most castings, as different sized sections of the casting will cool at varying rates, resulting in the setting up of new residual stresses.

Frequently, small repairs are not stress relieved, and hard spots will develop in machining either from the weld or adjacent metal in the case of high carbon or alloy castings, or from arcing either in the magnetic particle inspection or from striking welding arcs away from the repair area. This condition can be eliminated by proper stress anneal.

Rough Machining. This is not a repairing operation, but it is an operation which should definitely be taken into consideration in any repairs. If the casting is to be machined, many surface imperfections will be removed by the roughing cuts and internal repairs will be made more readily accessible or reduced in amount, so that wherever possible it is desirable to rough machine before repairing.

Intermediate and Final Tests. During the welding of large excavations it is sometimes desirable that tests be made to assure freedom from cracks, and it is frequently specified that each layer be magnetically tested by the prod method in at least two directions. No other method of inspection is applicable at this point due to surface conditions and/or time of inspection.

Upon completion of the repair, it is usually specified that the repaired areas be inspected. In some cases this refers to all repairs; in other cases to repairs which exceed a certain proportion of the thickness of the section.

Inspection should be made by radiographic means, either gamma or x-ray, depending upon the thickness of the section. This is the only method for the location of subsurface welding defects such as porosity, slag inclusions, and poor fusion.

Cracks in either the weld or base metal usually extend to the surface after the repair has cooled, and their identification by magnetic particle or other methods of inspection is not difficult. Final inspection of the casting should be made after all repairs and treatment have been completed to assure a quality product.

With the determination of the presence of any discontinuity, the work reverts back to the introduction of this paper, which discusses whether or not a certain discontinuity is a defect. If it is interpreted as a defect, the procedure of repair is repeated until all repairs have been determined to be satisfactory for the purpose intended.

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Industrial Status of
PRECISION CASTINGS

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● ***Sixteenth Century art castings and Twentieth Century gun parts produced by the same basic process. Developments in the precision casting process have made possible volume production of small, intricate parts allowing almost unlimited choice of materials.***

FOR some reason it seems that every time a new process is discovered its advantages and possible applications are greatly exaggerated until it is fairly well along in development. Precision casting is no exception to this rule.

Precision casting or investment casting, according to some people, is a new process which will, in the near future, undoubtedly make all foundries and machine shops obsolete. This is, of course, basically untrue since precision casting at the moment applies only to a relatively limited field and is most emphatically not a cure-all.

Some of the confusion apparently has arisen from what appears to be rather loose use of the words "investment casting" and "precision casting." To get a little closer to bedrock, the author proposes, at least as a starting point, some definition of just what these terms mean.

Investment Casting

The word "investment," in addition to involving those mysterious and profound transactions which will undoubtedly make our fortunes, also means covering or enrobing, and it is the custom of the dentist or jeweler to refer to a one-piece ceramic mold as an investment, since it completely covers the pattern and has no line of separation, i.e., no cope and drag.

Investment casting, therefore, should be defined as a metal-casting process employing an expendable pattern in conjunction with an unparted or one-piece mold. Precision casting is a refinement of investment casting wherein through certain techniques the resultant metal casting is held to tolerances not exceed-

Fig. 1—Example of Sixteenth Century casting by the investment molding process. *(Courtesy Art Institute, Chicago)*

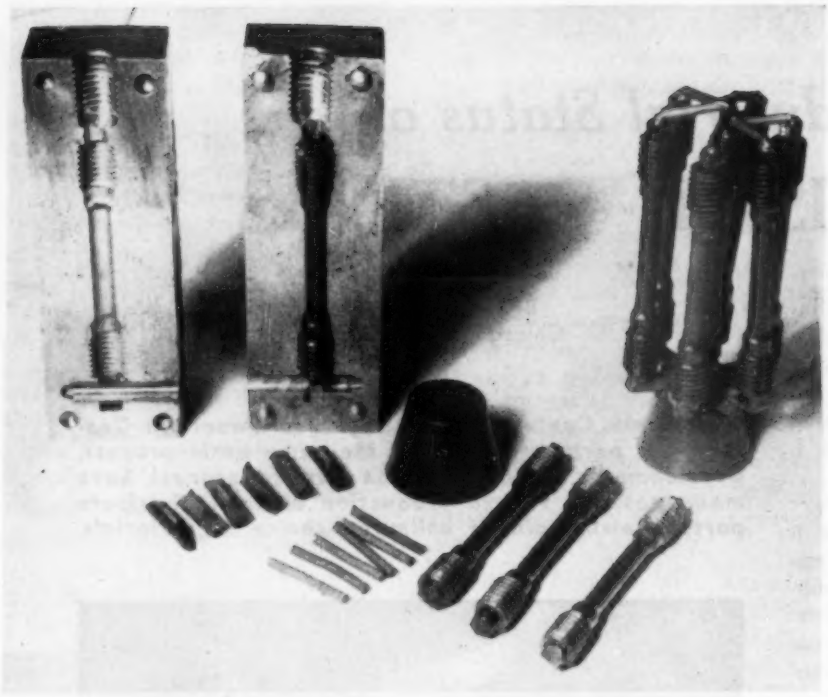


Fig. 2—Molding (left) and assembly (right) of the expendable pattern.

ing plus or minus five thousandths of an inch and having a surface finish at least "CF" or better. These definitions are admittedly open to considerable criticism and improvement, but they help to clear up some of the existing confusion.

Investment casting and, to a certain extent, precision casting, is one of the very old brand-new arts. Actually, Cellini in the Italian Renaissance period used investment casting to produce several of his art objects, such as "Perseus with the head of Medusa" (Fig 1). Since it was used for statuary, it must have had a certain amount of precision, although probably not as close as we would demand today.

It is doubtful that the process ever completely disappeared, and it is certain that for some time past it has been employed by both dentists and jewelers, particularly the former, to form low-melting-point metals into precise but irregular shapes.

Prior to the war, certain of the dental technicians had been working with the casting of non-ferrous alloys, such as Co-Cr-Mo alloy, and had been able to cast this material successfully into precision shapes required in dentistry.

Since Co-Cr-Mo alloy has a melting point of slightly over 2400° F., it was obvious that the process was getting out of the lower-melting-point phase and approaching steel-casting temperatures. Although the process itself will be covered in greater detail later in the paper, a brief review of the general procedure in making investment castings is in order at this point.

Forming the Pattern

The first step is to accurately form the pattern of some material, such as wax, plastic or low-melting-point alloy, which can be melted or burned completely out of the mold and having no residue (Fig. 2). All three types of patterns are in use today, wax being the most popular at the moment.

These patterns are then attached to sprues, runners, and a button or entrance gate and coated by dipping or spraying with a primary investment (Fig. 3), which normally consists of a finely divided sand with a binder and other materials. Other processes do not employ a primary investment, as will be seen later.

When the primary investment has set, the pattern is attached with the entrance gate downward to a metal or rubber plate, and a container, usually of stainless steel, telescoped over the pattern. An investment material is then poured into the container (Fig. 4) and thoroughly tamped to settle the investment material closely around the pattern.

This investment material consists of a ceramic aggregate, usually sand and/or grog, together with a binder having good refractory characteristics, such as tetraethyl orthosilicate, which upon ignition forms a network of SiO_2 binding the grains together. After tamping this material is allowed to dry for varying periods of time, depending upon the technique employed, and is then placed in an oven or steam bath which melts out or vaporizes the pattern.

Heating the Mold

Since the next step is to heat the mold to temperatures in excess of a 1000° F., the product will be a ceramic mold without any parting line and having a perfectly formed cavity which was formerly occupied by the expendable pattern. The molds are placed in a casting machine while hot and molten metal of the proper temperature is forced into the cavity under some type of pressure, this pressure being generated by air (Fig. 5), by centrifugal force or, in the case of ordinary investment casting, by static head only.

The metal is allowed to solidify under pressure, permitted to cool and subsequently the ceramic mold is broken away from the casting. The castings are then cut from the sprues, visually inspected, sand blasted, cleaned, x-rayed, etc. If properly cast, substantially no machining other than removal of the sprue is necessary.

The impetus given to this process by the war has been enormous. It is believed that the Air Corps was the first of the Armed Services to become interested in the process due to the urgent need for large quantities of turbosupercharger blades, which must be made of heat-resistant alloys difficult if not impossible to machine.

Much credit is due to companies which worked on this process and solved its problems over the trying years we have seen. Suffice it to say, however, that the production is going forward on a large scale and is meeting our needs at costs which immediately prior to the war were considered practically impossible.

The Ordnance Department having somewhat similar problems was also greatly interested in precision casting, but its requirements natur-

ally differed from those of the Air Corps. Ordnance was interested primarily in the casting of many different intricate parts from SAE and NE alloys, which proved to be the most difficult of all to cast.

The non-ferrous alloys appeared to be non-corrosive to the molds employed and fairly easy to cast, but the SAE steels, including the high- and low-carbon steels are highly corrosive and very difficult to handle. However, by careful control of the materials, times, temperatures and pressures employed, Ordnance was able to obtain from various suppliers certain steel parts for testing.

At first the test results were erratic because of lack of adequate control in the casting process, but as these problems were more clearly understood control improved and with it the consistency of results.

A little over a year ago, it was felt that the process had progressed far enough to warrant comprehensive tests on certain small, intricate parts needed by Ordnance. At that time it appeared that the vendors were able, within reason, to produce castings of 4140 and other similar alloys on a production basis to tolerances of the order of three thousandths of an inch and having an "f" finish.

Although there had been previous test work conducted on various parts for cannon breeches, the carbine was selected for test purposes since it was perhaps better adapted to precision casting and made in quantities sufficiently large to give an overall picture. The results of these tests were quite surprising.

Most of us are familiar with the carbine and realize that many of the parts are quite highly stressed. Certain of the parts in the carbine, such as the extractor, hammer, sear and trigger, were selected for test, and approximately 5,000 sets of parts were cast and assembled into complete weapons. Approximately 3,700 carbines were issued to troops for field trial. After firing about a quarter of a million rounds in these carbines, total damages occurring were three broken extractors.

Testing Carbine Parts

Some difficulty was experienced in keeping track of the test results, so these guns were collected and shipped to various arsenals and plants for further test. Here again the test results proved to be excellent and, in many cases, exceeded the life expectancy of machined parts.

One of the armories testing these carbines reported that they had fired 12,000 rounds in one, 6,000 in two others and 4,000 in another without any malfunctions, cracks, or breakages occurring in any of the cast parts. The only difficulties encountered were that certain of the parts appeared to be susceptible to premature failure at temperatures of — 40° F., and this was probably due to improper chemical control during the casting process.

One of the firms manufacturing carbines fired 65 of them, the quantities varying from 6,000 to 34,000 rounds. Since the extractors are the most critical and highly stressed parts, most of the test concentrated on these. All triggers, hammers, and sears functioned correctly and showed

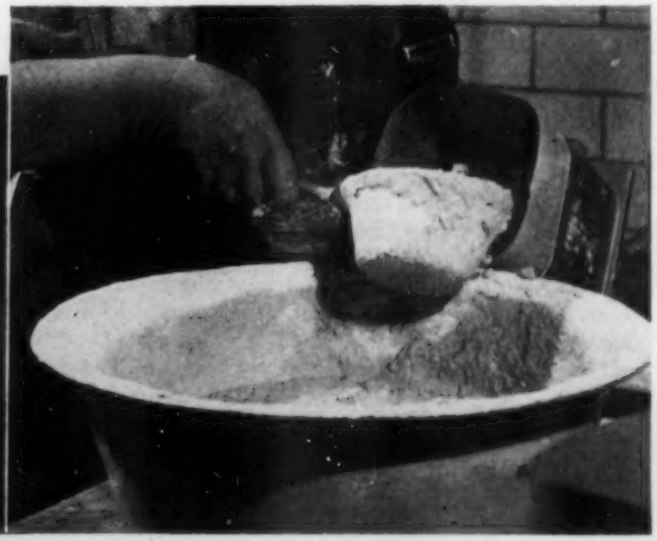
Fig. 5—Air pressure casting machine.

only normal wear after firing 17,000 to 34,000 rounds each, and no failure is expected in the remainder of the test firing.

In the case of extractors, 18 have withstood 17,000 rounds of firing, seven going to 20,000, three to 26,000 and one to 34,000 rounds. Only eight extractors had to be replaced at under 6,000 rounds, and of these three failed due to improper dimensions which, of course, should have been discovered at the source.

Since these tests appeared to be satisfactory, a check is being made for use in forming various machine gun parts. These tests are still in process, but at this moment it ap-

Fig. 3 (below)—Applying primary investment by spray method.
Fig. 4 (right)—Pouring investment slurry around pattern.



pears that the results will be equally satisfactory if not more so.

Status of Precision Casting

This brings us up to the status of precision casting today. As previously mentioned, the Army Air Corps is using this process to produce substantially all of its supercharger buckets, and is at least considering the production of similar parts, some of which are substantially larger. The ability of the process to supply the demand proves that it at least warrants classification as a production process, and not as a mere laboratory or pilot line curio.

Although the process should still be classified as an art and not as a science, because technique plays a large part in its successful operation, we believe that it is safe to state that practically any common metal which can be melted can be precision cast if its melting point is below 3000° F.

This, of course, opens up several interesting possibilities, particularly during the war, since it permits of the use of stainless steel in places where it would not ordinarily be employed due to difficulty in machining. By the same token, extremely hard alloys which would not have been used previously may now be employed in spots where great wear is encountered and so attain greater durability.

Another interesting development of this process is the ability to form magnetic materials with a high degree of precision and still retain excellent magnetic properties. This has been successfully accomplished and will undoubtedly play an important part in the design of future electrical components.

Casting Finishes

The finish possible to obtain today probably should be classified as an "f" finish or better, and this can be obtained in production. Finishes as fine as 3 microns have been obtained, and 65-micron finishes are currently obtainable on a production basis.

The process is gradually progressing from the batch process used by dentists and jewelers to the continuous straight-line technique which is necessary to large production. The production process possesses at least one great advantage over the dental process in that shrinkage may be corrected by correction of the pattern size, which is, of course, not the case in dental work where the cast pieces must replace exactly the dimensions of the pattern.

As would be expected, many individuals and companies have entered this field, and these include the usual assortment of good, bad, and indifferent. Considerable care should be exercised in selecting the vendor. The mere fact that he can submit one good sample does not necessarily mean anything. It is the reproducibility of the process that counts.

Process Control

Perhaps the most important single requirement today is the matter of control as applied to every step of the procedure, as well as the materials entering into it. Without control reproducible results could not be obtained, but with control reproducibility is exceptionally high, in many instances exceeding the reproducibility normally obtainable by machining (Fig. 6).

The physical properties of such castings are exceptionally good when properly cast under controlled conditions. While there are not yet sufficient data available to make any positive statements about physical properties, it appears that in most instances the tensile strengths and yield points will be comparable to bar stock of the same composition.

Castings of SAE 4130 steel can be made to yield tensile strengths of from 90,000 to 145,000 psi., depending upon the heat treatment, and will have a reduction of area from as low as 5 to as high as 35 per cent. This could be compared with 4130 bar steel having a tensile strength of 135,000 psi. with an elongation of 22 per cent. In general, it should be assumed that the elongation and reduction of area will be lower and perhaps 60 per cent of that obtainable in bar stock.

Metallurgical Control

Metallurgy is not yet under satisfactory control in all cases. The investment is a good insulator, which results in slow cooling and, as would be expected, this results in a normal dendritic structure which can be corrected by standard heat treatment. The grain size remains fairly large, sometimes as high as three. To at least some degree this can be corrected by casting in a cooler mold, if permitted by the contour and size of the piece, and by breaking the casting out of the mold as soon as possible after pouring.

Development of a more highly heat conductive mold would be very beneficial in this respect. When the density is high, as should be the case with good control, the cast parts exhibit an unusually high resistance to wear, perhaps due to the moderate chilling effect of the mold on the skin of the casting.

The existence of porosity varies with the supplier, but where good control is exercised rejects for porosity will be less than one per cent, based on 100 per cent x-ray inspection. Chemistry is under fairly good control and is attained usually by the melting of bar stock or similar scrap of known chemistry and making the proper additions for correction of heating loss.

Aluminum is normally used to deoxidize steel melts and is sometimes present in relatively large quantities. However, this is not objectionable in all instances and could probably be corrected if the necessity arose.

Dimension Tolerances

Dimensions are finally coming under close control, and at least one firm is today able to produce steel parts having tolerances of a thousandth of an inch to the inch or better in most instances. This tolerance control, of course, varies with the difficulty of casting the part and with the time devoted to the study of proper spruing, temperatures, etc. Close tolerances (Fig. 7) should not be required if not needed, as this increases rejects and costs.

When properly employed the process shows great possibilities in cost reduction. For example, figures developed by one of the arsenals for castings which cannot be termed precision castings but which are more truly investment castings designed simply to supply the machines with more closely formed parts for machining are shown in the table. It will be noticed that the cost reduction of certain of the parts is quite remarkable.

The Armed Forces as yet have not issued any blanket approval of this method, nor could they reasonably be expected to do so since the results obtained vary with the maker of the casting, but they have approved the use of this process for the manufacture of certain specific items under special controlled conditions involv-

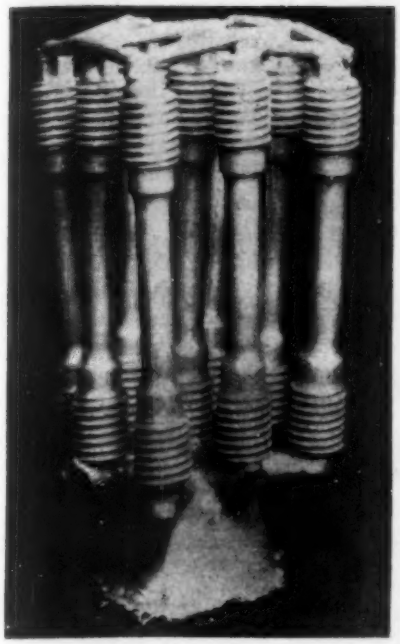


Fig. 6—Illustrating degree of precision generally available by precision casting in ferrous metals.

ing a high order of inspection. It appears to be a foregone conclusion that this will increase.

The cost of the process is still quite high and, while it varies within wide limits, a figure of 10 to 15 cents per ounce is not too far out of line for a rough estimation. This high cost is due not only to the current lack of mechanization of the process but to the high cost of the materials involved.

Costs in Precision Casting

Reclamation of pattern material is not always practical, and some loss of material is involved in every cost. In addition, the sands and binders are quite expensive. Skilled labor, fortunately, is not generally required for the process, and semi-skilled or unskilled labor can be quickly trained to perform the necessary operations.

Since spruing is very critical, both as to size and position, it is not always possible to stack the patterns in the most economical manner. This often means that only a small percentage of the metal cast goes into finished castings, and the amount of metal per lb. of sand is small. All of these factors contribute to the seemingly high cost.

The present equipment used in the process is, as will be seen later, still in its development stage, and a great many of the problems now present in the industry will disappear as the equipment is improved.

Since the process is still more of an art than a science, rejections will sometimes run quite high and are so variable that it is difficult to strike an average. One plant has reported a variation as low as 8 and as high as 80 per cent, while others figure 40 per cent as an average.

This may not present a true picture, however, since the inspection involved in these cases has been exceptionally high and the tolerances very close. A figure of 15 per cent would be as good an average as could be obtained today. These statements are deliberately quite vague since it is extremely difficult to obtain a clear picture of the status of this industry today due to the necessity for secrecy and the patent work which is always present in a new and growing field.

The process today, for practical purposes, is limited to smaller castings of the order of ¾-lb. or less. On the other hand, many larger castings have been made experimentally and could be produced commercially today if there were sufficient economic advantage.

Properties of Precision Castings

A word of caution, but this time on the credit side. If the physical properties of precision cast parts do not happen to be equivalent to the physical properties of bar stock which has been previously used in making the part, it should not be immediately assumed that the process is not suitable for making the part.

In many instances, the existence of a quality in the metal, such as tensile strength or elongation, actually may be immaterial in the functioning of the article. The real way to test is to cast the part and try it in comparison to its normal method of production. A true picture of value can be obtained in this way.

With regard to the future of the process, the writer would like to make a prediction. The prediction is that this process will probably be quite generally misapplied at first, and it is again emphasized that it should not be regarded as a cure-all. When properly applied it will cure a number of production headaches but, at least initially, its use should be confined to fields wherein it is obviously well adapted. At the moment, these fields can be fairly well defined in a general way.

This process is obviously excellent for the formation of relatively small parts made of unmachinable materials. Furthermore, it is quite well adapted to the manufacture of small, intricate parts where labor represents a large percentage of the total cost. Either of these factors, alone or in combination, would indicate that serious consideration should be given to precision casting.

Casting Design

It should always be kept in mind that the skill of the various people in the business varies, and poor initial tests from one group do not necessarily mean that the job cannot or should not be done, for another group may have the "know-how" required to make the job a success.

Before this process makes a serious impression on American industry, the author believes it essential that at least the existence of this process and its limitations get back to the designers who actually lay out the pieces. This is important for many reasons.

First of all, it gives the designer substantially complete freedom in his choice of materials. Second, he can combine in some instances several parts which were previously made as individual units for purposes of machining and form them into one unit. This is particularly important since the patterns can be assembled by means of suitable jigs and fix-

Comparative Costs of Machining and Precision Casting

	Cost of			
Part	Conventional Machining Methods	Precision Casting	Finishing Operations on Precision Castings	Precision Cast Part (finished)
A	$ 3.79	$1.05	$1.13	$2.18
B	6.50	1.00	2.16	3.16
C	4.97	0.75	1.35	2.10
D	4.66	0.45	1.09	1.54
E	11.90	1.60	2.09	3.69
F	10.76	1.32	2.64	3.96
G	2.30	0.65	1.11	1.76
H	14.27	2.00	7.56	9.56
I	7.35	1.84	1.49	3.33

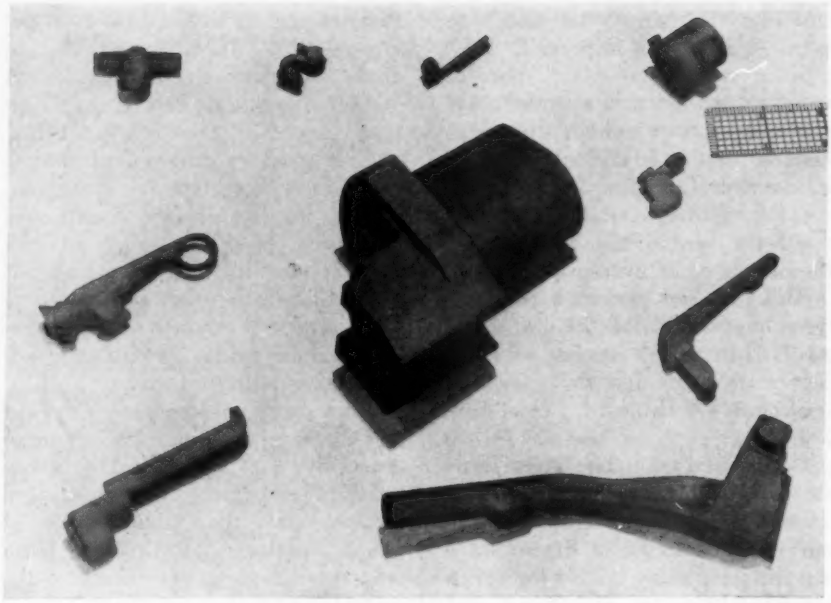


Fig. 7—Precision cast gun parts in as-cast condition. Close tolerances reduce subsequent machining costs.

tures into complex shapes after forming individually and the assembly cast as a unit.

It is important that the designer recognize that this is a casting process and, wherever possible, he should use good casting design, particularly in the incorporation of fillets, since sharp corners are always a source of potential weakness in an investment. Webbing may be employed to lessen weight, which would not be practical in ordinary design for machining.

He should not attempt, however, to design parts for precision casting which could be designed just as easily for use with automatic screw machines, punch presses or similar machines, since precision casting cannot compete on a cost basis.

Inventory Reduction

In addition to the possibility of substantially reducing machining cost and obtaining a better product, there is the interesting possibility of curing an inventory problem. For example, if we have an item or items which could be precision cast and for which we have a relatively large but sporadic demand, it is quite possible, in place of carrying a large stock of the product, to store only the die necessary to form the patterns.

The die being available, patterns can be supplied and casts made in a relatively short time, on the order of 10 days, which in normal times is sufficient to fill a good-sized order. Once this process is started the production per day with a relatively small setup is quite large and can be built up rapidly.

Still another factor in its favor is the speed with which parts can be obtained. Rather than waiting for the construction or removal from storage of jigs and fixtures, tearing down machines, etc., it would be necessary only to produce the patterns and cast the parts, a matter of a week or so, which does not disrupt either casting shop or machines.

Precision casting is not an industry into which anyone can move and do his own casting. Willingness to go through the research and development necessary to perfect the technique is necessary for success.

The effect of this process on various industries will naturally vary in almost direct proportion to the type of problems in the industry and the applicability of the process to these problems.

As for the process itself, granting that it is to assume an important place in the production picture, it is obvious that it must develop into a science and become highly mechanized with full control of all essential parts. With other improvements, such as hollow patterns, this will result in lower costs.

It is reasonably certain that a high order of accuracy and good physical properties can and will be obtainable wherever necessary, but that customers will soon realize that there is no object in paying for high precision unless it is really needed. The costs of castings will be proportional to the precision required, since the tolerances fundamentally control both inspection costs and rejections.

The author believes that there is little doubt that as the process accumulates more experience larger pieces will be cast, and that this eventually may provide a limited form of competition to some of the smaller articles normally cast in foundries. It is quite probable that 1945 will see the commercial production of 2.5 lb. precision castings, and that within 5 years precision castings weighing 10 lb. will be available.

Considerable doubt exists that the process will ever be applicable to large pieces of the type ordinarily handled in the average foundry, at least insofar as precision casting is concerned. However, this is not beyond the bounds of possibility and, as developments progress, may become more feasible than it now appears.

Acknowledgments

The author wishes to acknowledge the courtesies extended by the many organizations which have developed the various components of the precision casting process, especially to Austenal Laboratories, Inc., Chicago; General Electric Co., Schenectady, N. Y.; Allis-Chalmers Mfg. Co., Supercharger Plant, Milwaukee; Haynes Stellite Co., Kokomo, Ind., and the Illinois Precise Casting Co., Chicago, Ill.

• *A method for controlling sands by elevated temperature tests is being used by the author's company. Securing a good base sand and using the hot compressive strength test at 2000° F. forms the basis for the preparation and maintenance of a sand mixture suitable to any specific job. The balanced base sand is chosen from the results of "spall" tests, after which hot compressive strength values lying within a definite range are maintained in the ensuing sand mixture by means of clay manipulation. Use of this method results in reduction of scrap losses due to scabs and sand inclusions.*

Elevated Temperature Tests in SAND CONTROL

By Arnold Satz, Metallurgist,
The National Radiator Co., New Castle, Pa.

WHILE elevated temperature work with foundry sands has had a start within the industry, it has only recently crossed thresholds into the realm of practical sand control. The elevated temperature testing furnace has proved invaluable in revealing certain aspects of sand behavior at high temperatures. But still greater benefit may be expected as the device is applied to the control of daily sand preparation and reduction of scrap losses.

A practical method for elimination of scabs and sand inclusions in castings, as used by the author's company, will be described in succeeding pages.

Two Phases of Testing

Before a new sand becomes acceptable for application as the base material in sand mixtures for a specific job, its ability to withstand any hardship may be determined by studying the characteristic behavior of the material at elevated temperatures. Once this ability is ascertained, the second phase of testing with the elevated temperature furnace, maintaining a specific balance in the mixture, would give uniformly satisfactory casting results. This is accomplished by means of routine testing and adjustments.

Refractoriness, admittedly a very important quality in good sands, may be roughly determined in the elevated temperature testing furnace. Although this method is not nearly as sensitive as the present common procedure where a specimen is tested with a sintering meter, it offers a rapid check and an easy basis for comparison when choosing from among different new sands or mixtures.

Briefly, the adhesion of sand grains to one another after the specimen is subjected to a temperature of 2500° F. for 12 min. is the basis for judging refractoriness. Some samples of sand have been found to be hard, others could be crushed in the hand, after being submitted to this test. With intermediate degrees of incipient fusion being shown by scratch tests, the method does present a means for comparing sands or mixtures.

Besides being refractory in nature, the sand under consideration must resist spalling or cracking at elevated temperatures. In this determination, a green sand specimen is inserted into the elevated temperature testing furnace heated to 2500° F. Inspection is made after 2 min. to determine whether cracking occurred on expansion, and after 12 min. to observe whether spalling resulted due to both expansion and contraction. This test requires the use of two different specimens, one for each observation.

Nearly every foundryman is acquainted with Dietert's[1] example of a scab-forming sand. He has introduced the assumption that during the contraction cycle, a thin layer of sand buckles out into the molten metal filling the mold cavity. Where metal is able to slip behind the buckled sand a scab is formed, with the common metal-sand-metal sandwich effect resulting.

Scabs most commonly occur on flat sand surfaces, which readily act in the manner described. In a round section or one of uneven surface, any sand buckling would not readily produce a perfect bridge. It seems logical to assume that in this case a "peeling" of the outer sand skin would present a weak projection easily eroded by a moving stream of iron, and that sand particles would be carried into the mold cavity. In this way, a sand wrongly applied would give scabs to some castings, and impart dirt inclusions to those castings which were not readily apt to scab.

Cracking and Spalling

The elevated temperature testing furnace may either underestimate or overemphasize the seriousness of cracks and spalling in a specimen. A close sand used in radiation molding spalled badly in the testing furnace. Specimens were seen with bridged outer skin, or skin rolled back in the fashion of an orange

peel. Yet for light radiation work this sand gave only dirt-bearing castings, because a high hot strength was never developed in the sands on pouring. Sands used for heavy boiler work were similarly tested and found to have minor cracks; these sections bore scabs.

In correcting both sands, serious spalling in test specimens of the first was cut to a cracking state and dirt losses were reduced. When cracks were eliminated from boiler sand test specimens, scabs became fewer.

Balanced Sand Mixture

This behavior of sand specimens calls for careful analysis of any condition of cracking or spalling indicated by this test. The extent to which a sand specimen may crack before trouble can be expected with castings should be established by close relation of test and casting results.

By a balanced sand mixture, the writer means one that has a fairly narrow grain-size distribution and is intensively mixed. Such a sand mixture would react uniformly under all stresses imposed by hot iron.

Summarizing, the author and his associates find it important to have a well-balanced new sand and, therefore, use this measure of sand control. It is made certain that the new sand in use or about to be adopted will behave correctly in the furnace for elevated temperature testing. The testing temperature chosen is closely related to the casting size, and to the tendency of the sand mixture to scab or to yield sand inclusions.

Previous to the use of sand testing, foundrymen determined the value of the sand by "cut-and-try" methods, finally settling on the method giving good results most of the time. New methods permit of picking the best sand, and then exacting consistently good results by means of laboratory control.

Furnace for Control Purposes

Once a balanced sand of desirable qualities is in use, a method of control is necessary to maintain these properties. The method outlined here has been in use for over a year, is easy to apply and the results have been gratifying.

In addition to the "spall" tests, three other principal sand tests are possible when using an elevated temperature testing furnace. These are the expansion-contraction test, the hot deformation test, and the hot compressive strength test.

Throughout this paper, all reference to hot strength tests will imply the hot compressive strength test as opposed to other hot strength tests which may be in use or may be introduced later.

The importance of expansion and contraction in foundry sands has been emphasized by Dietert[1] and others. In applying results of elevated temperature tests in a practical way, however, this particular test leaves much to be desired. When the control method was first set up, it became clear that while expansion-contraction tests offered an insight into a sand's behavior, the test figures were not correlative with either scrap losses due to scabs or to sand inclusions. That it is difficult to change the expansion-contraction characteristics of the sand mixture is another reason for discarding this test.

Hot deformation, as a test, fell into disuse since, like the expansion-contraction test, it indicated behavior without showing a means for correcting adverse conditions. Besides, this test still lacks the accuracy essential in sand-control work.

Differing from the two foregoing tests is the hot strength determination. This type of test was found to be positively related to scab losses and losses due to sand-bearing castings. Use of this test for control is relatively easy and does not demand that any other properties which are required of a good sand mixture be sacrified.

Fields of Application

This laboratory has found that the use of hot strength tests in maintaining the same desirable properties in sands is a method applicable to the control of all moldings sands. The greatest benefits are secured for a continuous molding and sand system where constant testing with adjustment at the mixer is possible. For floor molding and special jobs, the method likewise is used in adjusting the properties of the sand so as to obtain results required for any specific type of work.

This method has been applied in control of sand mixtures used in skin-dried molding, and is more rapid than the tests using elevated temperature testing furnace specimens, the latter specimens being first oven dried.

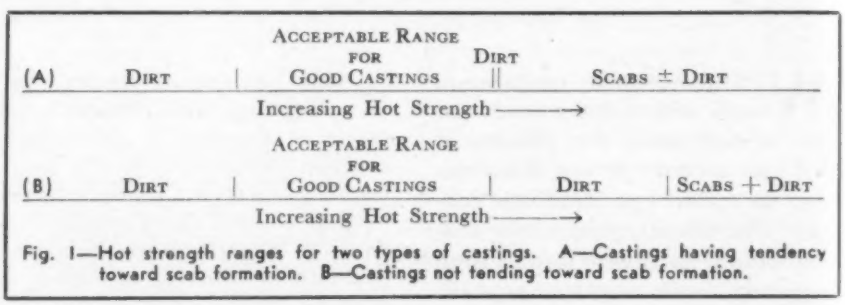


Fig. 1—Hot strength ranges for two types of castings. A—Castings having tendency toward scab formation. B—Castings not tending toward scab formation.

Hot Strength in Use

Every casting made requires a hot strength which falls within a certain range of values. Below the minimum acceptable hot strength value in the range, the sand will be cut or washed and the castings will contain dirt inclusions. On exceeding the maximum point in the range, castings bearing scabs along with dirt, or scab-free castings with only sand inclusions will result.

This last condition depends on the casting shape and indicates a condition explained previously. Throughout the acceptable or suitable range of values, castings will be scab and dirt free. A diagramatic representation of this phenomenon is presented in Fig. 1.

A number of factors influence the hot strength values lying within an acceptable range. These include

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green permeability, grain size, and method of gating.

To most foundrymen, permeability indicates the ease with which a sand vents mold-formed gases. Just as important, perhaps, is the function of permeability in venting heat. Observations made on sands at elevated temperatures have led us to believe that almost all defects resulting from a sand are due to the sand's behavior when heated rapidly by the pouring of hot metal.

Value of Permeability

A sand that spalls at 2500° F. may react satisfactorily at 2000° F. In another sense, the greater the ease of dissipating heat, the less will sand tend to form scabs. This function of permeability tends to broaden the range of hot strength values giving good casting results, and lessens the need for close control of moisture and clay content. Specifically, if good castings result when hot strength values range from 50 to 60 psi. at a permeability of 70, the range may extend from 45 to 65 psi. with an increase to 100 in permeability.

Many defects are guarded against when sands of very high permeability are used. However, modern practice demands closer attention to surface finish and imposes a restriction on the maximum permeability which can be maintained.

Although to the foundryman sand grain size and permeability are closely related, each requires different consideration in high temperature testing for hot strength. Dietert and Woodliff[2] have shown that hot strength changes with grain size.

Consider two sand mixtures having the same make-up with the exception that one has a finer base sand than the other. The hot strength values of these two mixtures will differ only because of a difference in grain size. Assume that good results are obtained with one of the mixtures having a hot strength of 80 psi. The second mixture, because of a coarser base grain, has a hot strength of 50 psi. but is to be used in broadening the range of acceptable hot strength values by its effect on permeability.

Since good results were obtained with the finer sand when the hot strength was 80 psi., the technician might think it advisable to add clay in order to raise the hot strength of 50 psi. in the coarser sand to the 80-psi. value of the finer sand. Scabs would no doubt result from this action, since consideration should have been given a lowering of the test results when the grain size was changed. Changes of this sort require the establishment of an entirely new range of acceptable values.

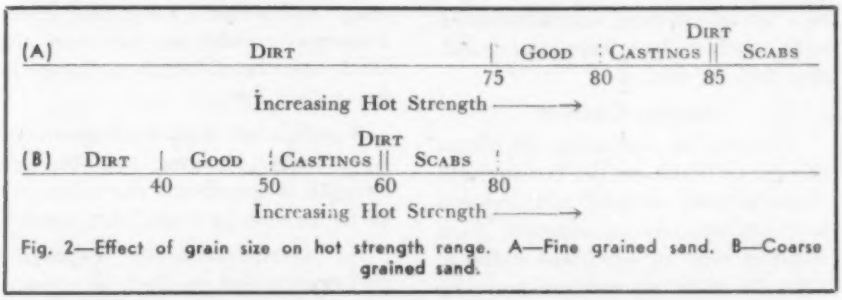

Fig. 2—Effect of grain size on hot strength range. A—Fine grained sand. B—Coarse grained sand.

Figure 2 represents this condition, showing that both sands could give good castings if used properly.

The example cited indicates that changes in size of sand grains affect the results indicated and that consideration must be given such factors as grain-size changes when interpreting test results.

Like consideration must be given any deviation from the temper moisture content in a test sample when determining the need for a change in clay additions.

Methods of Gating

One way of correcting scab formation and dirt inclusion lies in changing the method of gating. The hardship imposed on a sand by poor gating has the effect of limiting the range of acceptable hot strength values. Where conditions do not permit changes in a poorly gated casting, the burden of obtaining good castings is forced onto exacting sand control as a means of remaining within the acceptable hot strength range.

Collapsed Range

With an understanding of how the various factors tend to limit or to extend the range of acceptable hot strength values which give good casting results, it is possible to consider what happens when both scabs and cutting are found as defects on the same casting. The sand mixture giving this condition may be considered to possess no suitable hot strength range at all; that is, the range is collapsed since the particular mixture will not give good results no matter to what hot strength it is adjusted.

A lower hot strength attained in eliminating scabs would give a sand that might wash easily. A higher hot strength, achieved in order to eliminate wash, would give a sand producing scabs. A good example of this would be the use of a very fine sand for large castings. There is not much that can be done in making this sand work right.

The solution to a collapsed hot strength range lies in making one or more of the following changes:

1. Change base or new sand so as to get a well-balanced mixture which will not spall.
2. Switch to a higher permeability by use of a coarser grained sand. This will spread the acceptable hot strength range. Permeability may be increased just enough to provide a range sufficiently wide for easy control and inclusion of a safety factor, but not so much that poor finish results.
3. Change the method of gating so as to eliminate concentration of stresses on areas giving trouble.

These corrective measures probably are not new, but the method of determining where the source of trouble lies might be. We have found that testing at elevated temperatures is a positive means for telling when a sand does not suit conditions imposed upon it, for indicating what changes are needed and the extent of the required changes.

Testing and Controlling Sand

Once a satisfactory base sand is in use, only the hot strength test is run for control work. The 1⅛ x 2-in.

specimen, double-end rammed, is placed in the elevated temperature testing furnace without first being dried. All hot strength tests are run at 2000° F. without regard for pouring temperature. It has been found that hot strength test results can be correlated with casting results though almost any testing temperature above 1500° F. is used.

Application of Data

At 2000° F., so far as our experience goes, test results appear in a spread of values that permit easy application of data. This fact implies that results are sensitive enough to clearly indicate the effect of changes in moisture and/or clay content. In addition, values obtained at this temperature are not seriously affected by inaccuracies in the elevated temperature testing furnace, as those tests are run at much higher temperatures. The range of acceptable hot strength values at 2500° F. may be 1 or 2 psi., while at 2000° F. this range may be 10 to 20 psi.

All test specimens are compressed after a 4-min. recovery period plus 8 min. "at temperature" period. The hand-cranked hydraulic system is turned at the rate of 12 r.p.m. This rate was arrived at since it was found that a uniform motion could be maintained with the aid of a stop clock. Half revolutions of the crank correspond with 2½ and 5-second points of the sweep second hand. In this way, three operators at the author's plant are able to check each other closely.

Should test results indicate a hot strength other than that specified for a given job and sand condition, corrective measures are taken immediately. Three types of clay bonds are used in getting a desired condition—a western bentonite, a fireclay, and a southern bentonite. The procedure of effecting the changes outlined by Dunbeck[3] closely resembles that followed by this laboratory.

Clay Bond Additions

In reducing a high hot strength, new bond-free sand is added, with southern bentonite being used in quantities sufficient to maintain the required green strength. For increasing hot strength, the western bentonite is used, while intermediate values are obtained with the fireclay.

The foregoing procedure is followed with both facing and backing sands whenever a change is needed.

Naturally-bonded sands used for re-bonding "floor" sand mixtures function as hot strength raisers and, while the quantities added can be adjusted to correspond with requirements as indicated by test, the ease of control is not equal to that possible when using a synthetic sand and clay additions.

In all cases, control is kept fluid, with correct hot strength values the goal for any change made.

The moisture content is kept at temper, but there may be cases where the moisture content is so high that it causes too great an increase in the hot strength. Where this occurs, southern bentonite may be substituted for western bentonite, or a mixture of new, unbonded sand, with southern bentonite for rebonding, may be used.

Moisture Content

A system for evaluating the effects of various bonds on the hot strength characteristics of sand mixtures has been set up. As an example, each quart of western bentonite added to 1200 lb. of facing mixture increases the hot strength (at 2000° F.) by about 9 psi. Cutting the hot strength of system (old) sand used in facing preparation is accomplished by adding a new, unbonded sand.

When the facing contains 25 per cent of new, unbonded sand, a reduction of 20 psi. is expected in the hot strength of the mixture. It is assumed that southern bentonite does not increase the hot strength by any significant amount. Thus this material may be used in maintaining proper green strength without affecting the hot strength.

Moisture is very effective in raising the hot strength of sands. In this fact lies the importance of close moisture control, if scabs are to be eliminated. Every attempt is made at keeping the moisture only at temper, but steps are taken to maintain a range of hot strength values sufficiently wide so that normal increases in moisture throughout the day will not cause hot strength values which might soar into the trouble zone.

Whereas these values would not exactly apply in other foundries, similar evaluations could be set up. Of importance is the fact that conditions are maintained whereby changes may be made to compensate for any variation in the rate of "burning out" clay, or the rate of adding new sands to a system. Thus the elevated temperature testing furnace assumes the role of indicating needed changes, which can be made as conditions require and before difficulty is encountered.

Conditions relative to setting up the most suitable hot strength range have been considered. It has been found advantageous to inspect castings closely as soon as possible after shake-out to ascertain that the proper range is in use. Should scabs be found when sands are held in what is thought to be the proper range, and it is known that no "wet" streak of sand had been encountered, the maximum point of the range is lowered. Excepting under abnormal conditions, however, the sands have been found to change in gradual swings.

A reason has been established and is presented showing why the hot strength is considered the important factor in scab and sand-dirt control.

As stated previously, expansion and contraction in sands at pouring temperature are the conditions thought to cause sand spall, with resulting scabs or dirty castings.

Sand Embrittlement

It appears as though a sand becomes more brittle as the hot strength increases. Much as a brittle metal resists deformation, sand will not react to heat uniformly but will "give" even though hot shrinkage be of a magnitude so small as to be labelled satisfactory by an elevated temperature testing furnace expansion-contraction test. Thus, embrittlement decreases a sand's ductility at pouring temperatures.

That dirt inclusions due to a low hot strength result from a wash effect is a generally accepted fact.

To more clearly tie in hot strength with scab formation, one has only to consider what action was taken in the foundry with which the author is associated before introduction of this method. Generally, when scabs were found, first attention was given to moisture content. Since water is the most potent substance for increasing hot strengths, a reduction in hot strength accompanied

any cutting of the moisture content.

In cases where it was known that temper was not exceeded, another means of reducing hot strength[4] (reduced ramming) was tried. Another way of lowering scab occurrence was found to be in effecting a reduction in green strength. This also meant cutting the hot strength by reducing clay additions.

Permeability often was increased as a solution to scab problems. Although not a means for reducing hot strength, it did extend the hot strength range so that were scabs to appear at a given value, the new permeability would extend the range and the given value then would be lower than the maximum allowable hot strength for defect-free castings.

Summary

Summarizing, casting losses due to scabs and dirt inclusions were reduced by adhering to the following procedure:

1. Choosing new base sands on the basis of spall tests.

2. Maintaining a hot strength range which will give good castings by correlating test results with casting results.

3. Maintaining desired hot strength value in the sand by continuous changes in clay additions when the need for such changes is indicated by test results.

4. Adjusting the hot strength range when necessary by changes in the sand grain size.

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COLORIMETRIC DETERMINATION

of

Nickel and Chromium In a Combined Form of Analysis

• Progress in metallurgy and engineering indicates that postwar composition and physical property specifications for castings will be more exacting. The development of an economical, reliable, and flexible method for routine control analysis of straight carbon and alloyed steels, and irons, enables foundrymen to meet requirements, both as to total amounts of alloying elements and limits for various elements present as residual alloys.

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ONE of the problems of the metal industry today, and during the postwar years, will be to conserve critical alloying elements in variable amounts, as found in high and low alloy steel and cast iron products as return scrap.

Also, to have adequate control of the chemical composition and resulting physical effects (hardenability, weldability, forgability, machinability, carburization, structural properties, etc.) of residual or tramp alloys that may be present in the molten metal, solid castings, ingots or finished metal products.

Technical control (chemical and physical), adequate inspection, and properly written specifications will play a leading part in the buying of quality castings and metal products in the postwar era. This responsibility will fall on up-to-date purchasing departments where personnel has been developed and trained to obtain, under written specifications, the most value for the employer's dollar.

For the foregoing reasons, the author feels that the combined form of analysis, originally developed in Chain Belt Co. Metallurgical Laboratory, in conjunction with colorimetric determinations, offers a more economical, accurate, rapid, reliable, reproducible and flexible method for routine control analysis of straight carbon and commercial alloy steels, and irons, than is offered by the older conventional methods.

The following method for nickel is a modification of the Murray and Ashley colorimetric determination.[5] The method of Murray and Ashley has been used with some success, although it has certain undesirable characteristics due to the change in color developed after the addition of dimethylglyoxime.

This effect is more pronounced, and the results are less reproducible, where amounts of less than 0.50 per cent nickel are involved. Since one of the problems of the metal industry will be to conserve critical elements in variable amounts as residual alloys, it is apparent that a rapid satisfactory method for nickel would be very desirable.

From experience, the author has found the following modified method as worked out in this laboratory to be readily reproducible, and to be particularly suitable for routine analysis when applied in conjunction with the combined method of analysis as previously outlined.[1, 2]

Due credit should be given to G. R. Makepeace and C. H. Craft, Menasco Mfg. Co., Burbank, Calif., for recommending the use of sodium hydroxide to stabilize the wine red color.[3] This has been improved upon by separating the iron with an emulsion of zinc oxide, thereby eliminating the interference of iron, especially on small amounts of nickel.

In other words, the nickel glyoxime color is developed on a colorless or water-white solution and any color that does develop after the addition of dimethylglyoxime is due entirely to the presence of nickel without interference of iron. An outline of how the colorimetric method for nickel and chromium is applied in conjunction with the combined method follows:

Treat a one-gram sample with 5 ml. of dilute nitric acid (1-1) and 20 ml. of perchloric acid (70-72 per cent). (If chromium is not desired, use 10 ml. of perchloric acid to dissolve the master sample.) Take to short of dryness (*do not bake*) as previously outlined,[1] with the exception that 1 ml. of perchloric acid is added from a burette, in place of nitric acid, to dissolve the soluble salts.[2] After filtering and washing into a 100 ml. volumetric flask, dilute to mark and mix.

Silicon—Finish as previously outlined.[1]

Manganese—Pipette out 20 ml., finish as previously outlined.[1]

Molybdenum—Pipette out 10 ml., finish by the colorimetric method.[1]

Phosphorus—Pipette 5 or 10 ml., finish by the colorimetric method.[2]

Revised Nickel Determination

Pipette out 10 ml. of solution from the 100 ml. volumetric flask and transfer to a 200 ml. volumetric flask, dilute to mark and mix with water at approximately 100° F. (1 ml. = 0.0005 grams). Transfer 50 ml. (0.0250 grams) of this solution to a 100 ml. Barrett separatory funnel (Figs. 1 and 2). Add 2 ml. of zinc oxide solution and shake vigorously to precipitate the iron, dilute to 100 ml. Allow precipitate to settle for 3 or 4 min. and draw off the bottom 50 ml., which will include the precipitate of iron hydroxide.

The remaining 50 ml. is transferred to a 100 ml. volumetric flask. (A 100 ml. volumetric flask may be used in place of the 100 ml. Barrett separatory funnel. After separating the iron, filter 50 ml. into a 50 ml. volumetric flask, the 50 ml. of iron free solution is transferred to a 100 ml. volumetric flask and finished as outlined.)

Standard Solutions

The following reagents (see Table) are added in the order given, mixing after each addition: 3 ml. of 10 per cent tartaric acid solution, 5 ml. of saturated bromine water, 10 ml. of concentrated, ammonium hydroxide, 3 ml. of one per cent dimethylglyoxime solution, 5 ml. of bromine water. After one or 2 min., add 10 ml. of 5 per cent sodium hydroxide solution and dilute to mark with water and mix. After 10 min., check at 475 mu wave length, using distilled water in the reference cell (Fig. 3).

The red color is stable, with no appreciable change after setting for a period of several days. This is not true for nickel contents of less than 0.10 per cent, and they should be checked within the first hour.

For nickel contents of less than 0.10 per cent, use 5 ml. of solution direct from the 100 ml. master solution and add 3 ml. of zinc oxide solution in place of 2 ml. Finish as outlined and divide results by two (2).

For each additional 1.00 per cent nickel present, add an additional 100 ml. of water to the colored solution. For example, for approximately 5.00 per cent nickel, transfer to 500 ml. volumetric flask and dilute to mark and mix, multiply results by five (5) to convert to percentage of nickel.

It may be of interest to note that this method for nickel may be applied to non-ferrous metals and alloys.

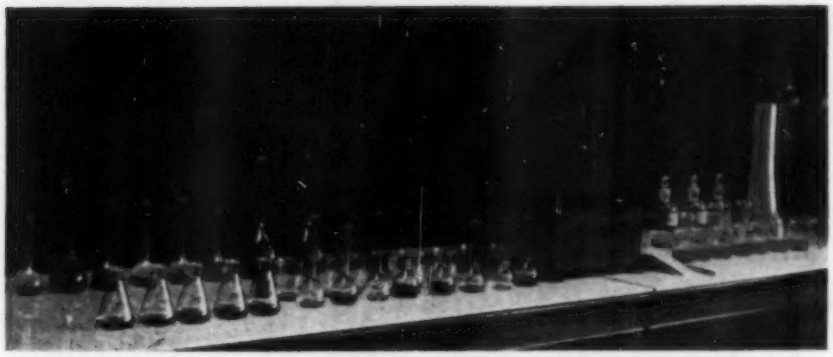

Fig. 2—Quantitative colorimetric solution as prepared for the determination of nickel, phosphorous, chromium and molybdenum. Table is especially constructed, with dull green background and milk glass top, to give visual contrasts of various colored solutions.

Fig. 1—Showing (at left) the six 100 ml. Barrett separatory funnels and support, as used for the separation of iron from nickel.

Determination of Chromium

Louis Singer and W. A. Chambers, Jr., Naval Research Laboratory, Washington, D. C., have applied the perchloric acid oxidation method for the direct colorimetric determination of chromium in steel.[4] Although the method has been in use for several years, Singer and Chambers are the first, to the author's knowledge, to apply it as a direct quantitative color method.

The basis of the method lies in the fact that ferric perchlorate, which is itself colorless, intensifies the color of the dichromate ion. The method is not subject to interference by the usual alloying elements. However, large amounts of alloying elements may produce appreciable error.

After having withdrawn aliquot proportions for manganese, phosphorus, molybdenum and nickel, the remaining master solution is used for the determination of chromium.

Analytical Procedure — If chromium content is less than 0.10 per cent, do not dilute the remaining oxidized chromium solution in the 100 ml. volumetric flask. Transfer 25 ml. of this oxidized chromium solution to a small beaker and reduce with one drop of reducing solution (0.0100 grams). Use this

reduced chromium solution in place of water in the reference cell. Compare at 455 mu wave length and apply curve *C* (Fig. 4).

If chromium content is from 0.10 to 1.00 per cent, adjust the remaining oxidized chromium solution in the 100 ml. volumetric flask to 50 ml., dilute to 100 ml. and mix. Transfer 25 ml. of this oxidized chromium solution to a small beaker and reduce with five (5) drops of reducing solution (0.0500 grams). Compare at 455 mu wave length and apply curve *A* (Fig. 5).

Above 1.00 per cent to 2.40 per cent chromium, reduce 25 ml. of the oxidized solution with 10 drops (0.1000 grams) of reducing solution, compare at 490 mu wave length and apply curve *B* (Fig. 5).

For chromium above 1.00 per cent, one may dilute approximately every 0.70 per cent chromium present with an additional 100 ml. of water, compare at 455 mu wave length and multiply by correction factor to convert to percentage of chromium.

Percentage of Error

Samples having a chromium content of between 0.10 and 0.30 per cent may use the remaining oxidized solution without diluting. Apply curve *A* (Fig. 5) and divide the results by two (2) to convert to percentage of chromium.

Due to contamination of the dichromate ion with silicic acid, an appreciable error may be expected if the silicon content is in excess of 1.00 per cent and the normal graphs are applied. However, for cast irons and steels containing higher silicon contents, supplementary graphs may be plotted against suitable standards of known silicon and chromium content.

The author would not recommend the method for irons containing approximately 2.00 per cent silicon and having less than 0.20 per cent chromium. One may expect the chromium percentage error to increase as the percentage of silicon increases and the percentage of chromium decreases.

An additional precaution is the amount of free perchloric acid present; for this reason we take the initial or master sample to short of dryness *(do not bake)* and redissolve the soluble salts with 1.0 ml. of perchloric acid added from a burette in order to have the acidity under control for the various determinations to follow.

For example, if 5 ml. of perchloric acid is used in place of one ml., low chromium values will result. Temperature of the final solution should be adjusted to within a few degrees of room temperature.

Singer and Chambers[4] add ferrous ammonium sulfate crystals (about 10 to 20 mg.) as a reducing agent. The author has found it necessary to have this reducing solution under closer control; this is especially true for amounts of chromium less than 0.10 per cent. It is also a means to establish a more relative constant factor for a given solution in the reference cell.

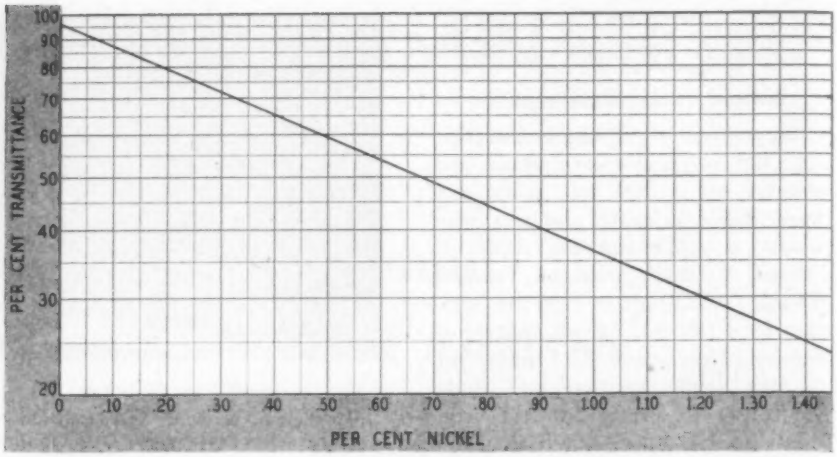

Fig. 3—Nickel in steel colorimetric determination. Sample, 0.0125 grams diluted to 100 ml. Wave length, 475 mu.

Standard Solutions*

Zinc Oxide

100 grams	Zinc Oxide
1000 ml.	Water

Tartaric Acid

100 grams	Tartaric Acid
1000 ml.	Water

Bromine Water

454 grams	Bromine
2000 ml.	Water (approx.)

Dimethylglyoxime

100 grams	Dimethylglyoxime
1000 ml.	Alcohol

Sodium Hydroxide

50 grams	Sodium Hydroxide
1000 ml.	Water

Reducing Solution (Cr)

	Ferrous Ammonium
5 grams	Sulphate
24 ml.	Water
1 ml.	Perchloric Acid

*Transfer solution to a suitable dropping bottle so that 20 drops will approximately equal 1.0 ml., or be equivalent to 0.2000 grams of the salt (1 drop equals 0.0100 grams). Make fresh solution each week.

Conclusions

Since colorimetric determinations require only a small amount of sample, it is evident that, by applying the combined method of analysis, a more representative sample is obtained by taking aliquot amounts from a large initial weighing of the sample, diluted to its proper volume, than can be obtained by direct weighing a few milligrams of sample.

It is also evident that an appreciable saving in chemicals results, since several determinations may be made from aliquot proportions from the master solution. Also, it is not necessary to use chemicals to dissolve individual samples for various

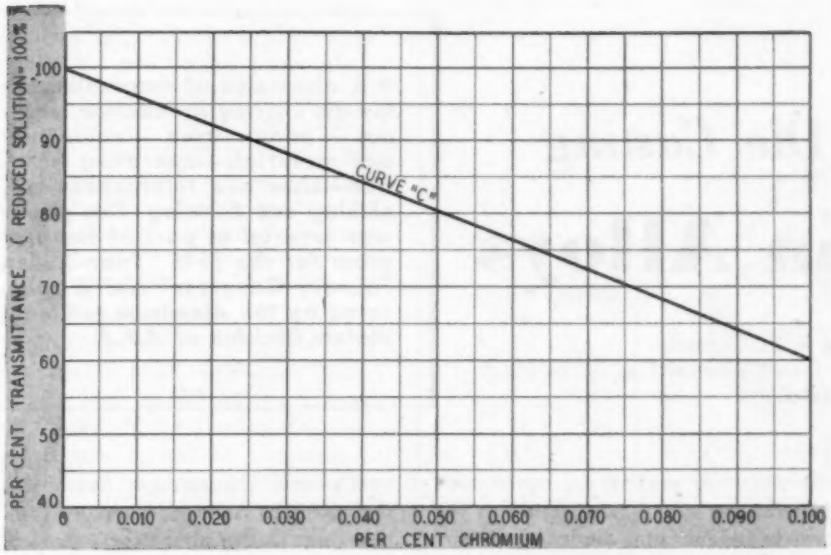

Fig. 4—Chromium in steel colorimetric determination. One-gram sample diluted to 100 ml., 25 ml. reduced with 0.0100 grams of ferrous ammonium sulphate. Wave length, 455 mu.

determinations, as required by the older conventional direct methods.

Calibration and analysis should be made under exactly the same conditions, using standards of near like composition. The values may be determined from a smooth curve as readily as from a straight line. The curve should be plotted in the wave length range in which the greatest change in transmission occurs with a change in concentration of the substance.

Should the highest degree of accuracy be required, this can be obtained by making several graphs of the various working ranges needed in any particular case. For example, the nickel curve (Fig. 1), plotted from 0.0 to 1.45 per cent nickel, could be broken down into five (5) separate curves, each curve covering a range of 0.29 per cent nickel and plotted in the wave length range in which the greatest change in transmission occurs for a given color or concentration of the element involved.

When working with solutions containing a high concentration of the element involved, close control of water temperature used for diluting, aliquots withdrawn from the master solution, and other factors should be under more elaborate control than for master solutions having a low concentration of the elements involved.

In the future, one may expect more rigid written specifications for the total amount and limits for various elements that may be present as residual alloys in a given metal product. Modern metallurgy and engineering will make this a necessity.

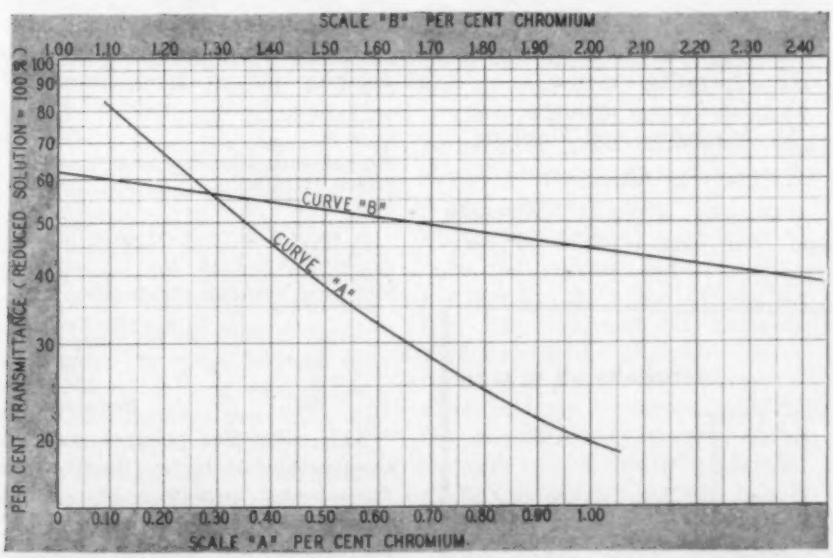

Fig. 5—Chromium in steel colorimetric determination. One-gram sample to 200 ml. Curve A, 25 ml. reduced with 0.0500 grams of ferrous ammonium sulphate. Wave length, 455 mu. Curve B, 25 ml. reduced with 0.1000 grams of ferrous ammonium sulphate. Wave length, 490 mu.

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Principles of Die Casting

Magnesium Alloys

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● ***A discussion of magnesium alloy die casting production methods — alloys used — equipment and materials—operating practice—sizes and tolerances—machining and finishing. This paper was secured as part of the program for the 1945 "Year-'Round Foundry Congress" and is sponsored by the Aluminum and Magnesium Division of A.F.A.***

IN THE present discussion, the term "die casting" is used to designate pressure die casting as contrasted to gravity or permanent mold casting. The die casting of magnesium is a relatively new art in that it has only been practiced in the United States for about the past 13 years.

The evolution of the process as applied to magnesium alloys has necessarily led to the development of a lot of "know how" which goes to make up the art of casting. Many of these practices are plant or trade secrets which are not generally available, but must be acquired through actual experience. Since it is a fairly new field, equipment and methods have not been sufficiently publicized and standardized, with the result that many of the practices which are satisfactory under one set of operations are not entirely useful under a different set of conditions.

It is the purpose of the following discussion to present an up-to-date general picture of the methods by which magnesium die castings are made. Magnesium die castings can be readily made by methods not greatly different from other metals, notably, aluminum. However, it is important that attention be given to the working details described herein if the best results are to be obtained. Differences in physical characteristics of magnesium alloys require certain deviations from methods used in die casting aluminum, zinc, and other metals.

The discussion will be broken down into the following headings:

I. Alloys
II. Equipment and Materials
III. Operating Practice
IV. Sizes and Tolerances
V. Machining and Finishing

I. Alloys

A number of alloys have been used from time to time for magnesium die casting and have been described by Winston[1]. At the present time by far the largest proportion of die castings are being produced in A.S.T.M. alloy No. 13. which has the following nominal composition:

	Per Cent
Al	9.0
Mn	0.2
Zn	0.6
Mg	Remainder

This composition combines good casting characteristics with adequate mechanical properties and corrosion resistance. It conforms to Navy Aeronautical Specification M-369 and Army Air Corps Specification No. 11319. Typical mechanical properties obtained on standard A.S.T.M. die cast test bars are:

Tensile Strength, psi.	33,000
Yield Strength, psi.	21,000
Elongation in 2 in., per cent	3.0
Brinell Hardness	60.0
Izod Impact, ft. lb.	1.5

A second alloy used to a limited extent is A.S.T.M. No. 12, with the following nominal composition:

	Per Cent
Al	10.0
Mn	0.13
Si	0.5
Mg	Remainder

This alloy has been claimed to have somewhat higher fluidity, but shows lower corrosion resistance and somewhat lower elongation and impact properties. Typical properties on standard A.S.T.M. die cast test bars are as follows:

Tensile Strength, psi.	30,000
Yield Strength, psi.	22,000
Elongation in 2 in., per cent	1.0
Brinell Hardness	62
Izod Impact, ft. lb.	1.3

Recently, a grade of alloy No. 13 of controlled high purity and designated as A.S.T.M. No. 13x has been available for casting. This alloy has use where maximum corrosion re-

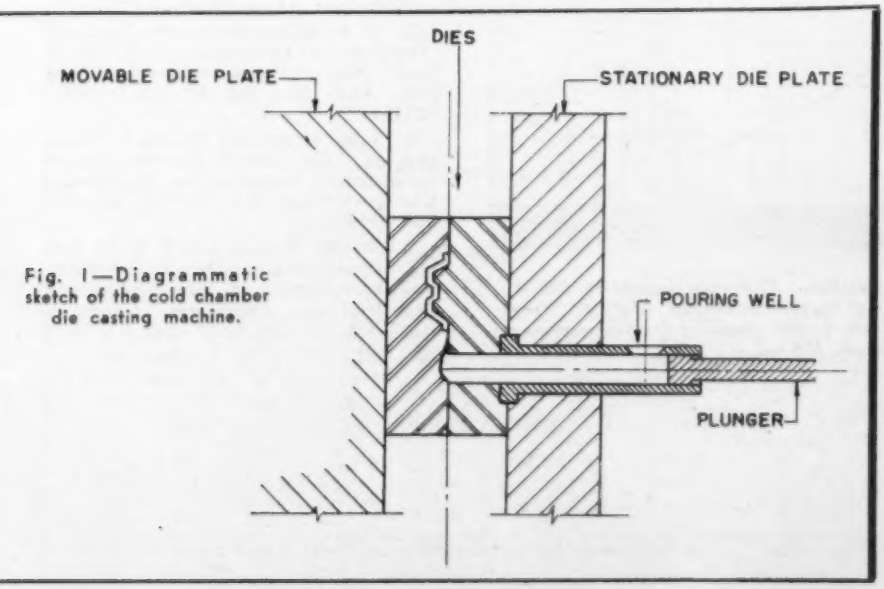

Fig. 1—Diagrammatic sketch of the cold chamber die casting machine.

sistance is required. Since die casting pot and casting temperatures usually are low, these pure alloys can be handled conventionally.

The addition of a very small amount, approximately 0.001 per cent, of beryllium has been made in some die casting plants in order to retard oxidation in the molten state.

II. Equipment and Materials

Die Casting Machines

High pressure, cold chamber type machines are most satisfactory, pressures as high as 50,000 psi. being used. Probably the average die casting pressure range for magnesium alloys would be around 4,000 to 15,000 psi. Low pressure machines, such as the gooseneck type operating at 400 to 600 psi., are not generally recommended. For general purposes, machines with die locking pressures of the order of 400 to 500 tons are desirable, due to the high injection pressures commonly used. Die clamping capacities would have to be considered in relation to the injection pressures in order that there will be sufficient locking pressure to keep the dies closed on the castings with the largest projected area which one would propose to make on the particular machine. It is very important that the machine have adequate strength and rigidity. The diagrammatic sketch of a typical cold chamber machine is shown in Fig. 1.

Figure 2 shows the diagrammatic sketch of the type melting pot in most common use for the die casting of magnesium alloys. The molten metal is protected against oxidation by means of SO_2 fumes generated in the double-walled dome shown in the sketch. The space between the walls contains a layer of sulphur, and the heat from the pot causes the sulphur to melt and sulphur vapor to issue through holes or slots surrounding the ladle opening in the sides of the cover. The sulphur vapors burn on contact with air, thus providing SO_2, which effectively inhibits active oxidation of the molten magnesium alloy at the operating temperatures between 1100° F. and 1300° F.

The pots are generally of 450-lb. magnesium capacity and are made of plain carbon cast steel. They are normally placed in brickwork settings and fired by either oil or gas. At the low temperatures of pot operation for magnesium die casting, such pots, even without any special protection, will often last as long as several years. However, they should be inspected very carefully at least once a month, and at such time any accumulated scale or oxide should be removed from the furnace settings.

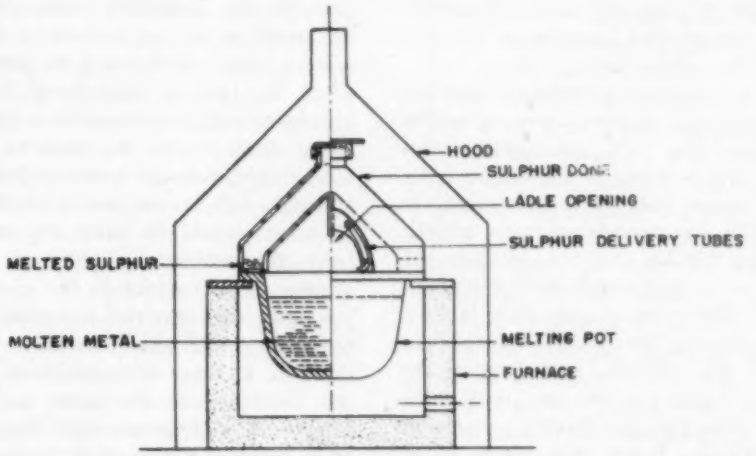

Fig. 2—Sketch of melting and protecting system for die casting magnesium alloys.

It is important that automatic temperature control be available for the die cast melting pots. Either galvanometric or potentiometric type controlling instruments are adequate, the former being cheaper and just as satisfactory for the purpose.

Thermocouples may be Chromel-Alumel or Iron-Constantan and should be protected in the pots by a steel pipe or sheath.

Fluxes and Agents

In the melting and refining of magnesium alloys for die casting, Nos. 220, 310, and 230 fluxes are used. The exact procedure for the handling of the molten metal will be described later. Protection agent No. 181 or 190 is also required during sludging and skimming operations.

Ladles, Skimmers, and Sludging Equipment

Die casting ladles are simply round-bottomed steel dippers with a handle about 18 in. long. The capacity is governed by the size of the casting to be made, and thus serves as a satisfactory metering device. A satisfactory skimmer can be made by welding a ¼-in. screen bottom to a 1½-in. length of 6-in. steel pipe. The handle should be long enough to suit the pot size. Sludge and flux pans may be of ordinary boiler plate construction made up to convenient sizes and shapes to permit easy removal of the frozen cake.

Die Design

Dies for casting magnesium alloys may be made from a number of tool steels on the market. For relatively short runs a carbon tool steel is satisfactory. For long die life a tool steel of the 5 per cent chromium-6 per cent tungsten type has been found satisfactory. The dies should be heat treated and drawn to a Brinell Hardness of about 400 to 450. The drawing temperature should be 1050 to 1175° F. so that the dies will not soften in use.

III. Operating Practice

Melting Practice

The sulphur dome melting method is used almost universally in this country for providing metal for die casting operation. It is considerably different from any of the other magnesium melting practices in that it uses No. 220 flux, which has the characteristic of being able to refine the metal, but does not have the property of giving surface protection. Since the die casting process requires the introduction of a ladle into the pot many times per minute, the use of a flux that gives surface protection might lead to the inclusion of flux in the metal because of the continued agitation. For this reason No. 220 flux has been definitely designed to do the refining and then settle to the bottom, so that it may be completely removed from the pot with the sludge. Surface protection in this pot is provided by an atmos-

phere of SO_2, which usually is generated by burning sulphur in a hollow dome that operates as a cover for the melting pot.

The ladle is introduced into the pot through a small opening in the cover. The SO_2 generated within the hollow dome is allowed to enter the space just above the metal in such a way as to blanket the molten metal surface and to inoculate the air entering through the ladle opening. The primary meltdown is done by dusting the surface of the pot with No. 220 flux and charging the solid metal into the pot, with careful attention and fluxing to prevent oxidation. When the batch is all molten, it is stirred thoroughly with the flux to agglomerate the oxide. It is next allowed to stand for about 10 min. to permit settling of the sludge and flux. The melt is then ready for sludging, which consists of removing the sludge with a skimmer perforated with ¼-in. holes. The skimmer is preheated and put into the metal, scraping the bottom and sides of the pot.

Sludge Removal

When the skimmer is brought up with the metal and sludge, the molten metal runs through the perforations, leaving only the sludge, which is dumped into a preheated pan. After the sludge is removed from the bottom of the pot any dross or unsettled flux is skimmed from the surface and the metal should now appear clean and shiny. It is advisable to allow about 10 min. quiet standing before beginning to dip metal from the pot. The foregoing procedure is followed in starting up a new pot, but in normal operation it is preferable practice to keep the die casting pot relatively full of metal. This may be accomplished by adding fresh ingot at a rate sufficient to maintain a constant metal level, or, still better, do all of the melting in a separate premelting unit, using No. 230 flux and then transferring molten, refined metal directly to the casting pot by tilting or ladling from the premelter as convenient. If scrapped castings, butts, gates, etc., are charged into the premelter along with ingot, it is preferable to use No. 310 flux for the premelting. The melting of scrap is discussed later.

The usual pouring temperature range for die casting is from 1175 to 1250° F., so the oxidation tendency for the metal is relatively low. Due to the protective atmosphere the metal in the pot acquires a thin surface film, which must be parted when the ladle is introduced. It is always desirable to maintain a clean metal surface since this reduces the rate of oxidation and leads to cleaner castings. Any accumulation of dross or crust should be skimmed away from the surface or edges of the molten metal surface in the casting pot since this material is sometimes pyrophoric and may lead to a pop or flash. If there is evidence of undue oxidation on the metal surface after ladling, it means that the sulphur dome is not working properly. Sometimes a very slight dusting of sulphur or other similar agent on the edge of the dome may be required to control oxidation. In no case would fresh flux be added to the pot unless the entire refining and sludge removal processes were to be repeated. In continuous operation, particularly if ingot is added directly to the pot, it may be necessary to reflux the pot every 4 to 8 hours. Ordinarily, from 1 to 3 per cent of No. 220 flux is used.

Unless absolutely unavoidable, it is not good practice to make alloy or alloy additions in the premelting or die casting pot.

Scrap Melting

The melting and refining of die casting scrap presents a special problem different from that for the bulk of magnesium scrap, in that a certain proportion of carbonaceous materials, lubricants, etc., is present on the scrap, so that melting and refining in No. 230 flux, as in ordinary practice, is not satisfactory. A reddish scum, or film, of the carbonaceous material seems to stay suspended throughout the metal. This behavior is eliminated through the melting of such scrap in open pots or crucibles, using No. 310 flux instead of the usual No. 230 flux. The No. 310 flux has the characteristics necessary to agglomerate the carbonaceous film and refine this material. Melting procedures are similar to the open pot operation for scrap recovery, except for the substitution of No. 310 flux.

Composition Control

Composition control usually is maintained by the following procedure:

1. Using certified alloy ingot.
2. "Blending in" premelted and refined die casting scrap of known composition which is periodically analyzed in the premelting unit or in the actual die casting pot.
3. Certification of the cast product on the basis of analyses of randomly selected castings from a given lot of actual castings.

Die Temperatures

Die temperatures ordinarily run from 250 to 600° F., with 400° F. as a good average temperature. Heat is applied to the die by electric strip heaters or a gas torch. Care must be taken that the heat supplied to the dies is as uniformly distributed as possible, so that warpage is prevented. In continuous operation, temperature of the die is maintained, and heat need be applied only after interruptions. In regular operation, the heat is maintained in the dies by balancing the production rate. It is sometimes found that water cooling channels in the die are needed to limit the temperature to the desired degree. The optimum operating temperature for the individual die can be found only by actual operation. In general, however, castings requiring a large amount of metal will require water cooling of the die. Freedom from surface swirls and cold shuts is possible only when dies are maintained at the proper temperatures. The dies gradually become coated with a thin film of oxide, making other die coatings generally unnecessary. Too high die temperatures may cause excessive oxide film on the dies and rough surfaces on the castings.

When all conditions of the metal and dies are ready for casting, the pouring ladle is preheated on the rim of the pot before introducing it into the molten metal. After this preheat, the ladle may be held under the surface of the molten metal in the pot to bring it up to the metal temperature. This will prevent the metal from freezing to the ladle in the dipping operations. The ladle is filled by parting the protective film with the back of the ladle and dipping the ladle into the bath. The ladle is then lifted from the pot, transported to the machine, and the contents poured into the well, the injection being applied or the shot being made as soon as the last bit of metal from the ladle has been poured.

Operation Timing

Accurate timing of this operation and the shot speed is essential to constant production of good quality castings. Only experience on a given job will tell how soon the die should be opened after the shot. If, on repeated ladling, spots of burning occur on the surface of the molten bath, they may be extinguished by a sprinkle of protecting agent No. 181 or No. 190.

The usual pouring temperature range for the metal is 1175 to 1250° F., depending upon the design of the casting being made. When it seems necessary to go above 1300° F. in order to obtain a good casting, the remedy should be sought in improved gating. In no instance should a pouring temperature of 1300° F. be exceeded, since sulphur dioxide will not provide sufficient protection for the metal at this temperature. The lowest casting temperature that will result in sound castings should always be sought.

Uniform Conditions

In starting to make castings after an interruption in production, it usually will be necessary to make quite a few castings before the die temperature and conditions become uniform. Until such conditions are stabilized, it is difficult to tell whether the particular casting setup is adequate for the job.

It is common practice to use lubrication on the injection plunger. Graphite type greases similar to those used in the cold chamber casting of other metals are recommended. The amount of lubricant used should be held to the minimum necessary to accomplish the desired result.

The gating method is undoubtedly the most difficult and, at the same time, most important phase of the operations upon which to make recommendations. It will be obvious that correct gating will depend on the size and type of the casting, as well as the equipment available.

Die design for magnesium generally is similar to that employed in aluminum die casting practice. The gates and vents will require special consideration. Large fillets, careful blending around section changes, and the rounding of sharp corners are advantageous. The following additional points may be of assistance as general considerations in the layout of the die:

(A.) It is of primary importance that the metal be placed in the die with a minimum of turbulence. In general, this can be most readily accomplished by bringing the metal in from the bottom. The effect of cores, thickness of section, and other factors in the casting shape which might lead to channeling or interference with the smooth flow of the metal must be considered and proper gating provided to minimize these effects. These points will have a direct bearing on the surface quality and soundness of the part.

(B.) Proper venting of the die cavity is also of paramount importance. Vents usually will be most effective near the top of the cavity, but may also be required at any other point where, due to the shape of the casting, entrapment of air might occur. The use of overflows or pockets which will permit some metal to flow out of the main die cavity at certain points which are otherwise difficult to fill is advantageous in many cases. Ordinarily, ejector pins and cores are so adjusted as to give as much additional venting as possible.

(C.) Gating should be so designed as to minimize the amount of hot metal flowing over any small area within the casting cavity, since this may lead to casting defects, as well as excessive accumulation of oxide on the die. Excessive oxide accumulation will lead to adhesion of the casting to the die cavity and may produce shrinks and cracks.

(D.) Much can be accomplished toward the improvement of soundness by the use of controlled injection speeds coupled with higher pressures. As a generality, most magnesium castings achieve the best surface quality through the use of injection speeds much higher than those normally used for aluminum.

Quality Control

Surface inspection of the casting occurs at three stages in most plants:

(1.) Hot inspection at the machine is made hourly on a representative number of castings. The purpose of this inspection, which is carried out by the regular inspection personnel, is to keep Plant Supervision, Casting Supervision, and the Chief Inspector constantly informed on the operation of each job. This procedure helps prevent a large quantity of scrap castings from being run before a particular defect is noticed.

(2.) Rough inspection of the castings takes place before the castings enter the clean-up department. Generally, this inspection is rather cursory and is carried out by the trim department for the purpose of avoiding the wasted labor of trimming obvious scrap.

(3.) It is generally preferred to carry out the final inspection after the castings have been given the chrome-pickle treatment. This final inspection is handled by the regular inspection department.

X-ray Inspection

Most new jobs are started out with the help of the x-ray. This has been found to be the most economical way of developing the proper venting, gating and casting procedure, even though the production control of the job may not require x-ray inspection.

If x-ray inspection of a job is to be carried out, it is done in accordance with the purchase specifications. In any event, it has been found good practice to radiograph a few castings after a part has been out of production for a time as a check on previously established practices.

The hazard of molten metal spitting out at the die parting line during the casting stroke is common to all types of die casting, and machines and working areas should be so located that occasional metal spitting cannot possibly contact personnel or inflammable material.

As has been previously discussed, it is very important that ingots, ladles, thermocouples, sludge pans, and other tools or utensils be fully preheated before coming into contact with molten metal or flux. Moisture or water coming into contact with molten magnesium can cause serious accidents.

Valves for fuel and air supply to the burners should be so arranged that they can be shut off at a safe distance from the melting and casting area in case of an emergency.

Fireproof Clothing

It is recommended that men working with molten magnesium wear fireproof clothing. The use of a face mask, fireproof flannel shirt, and leather chaps which cover the body from the waist down over the shoe-

tops gives proper and effective protection. An effective fireproofing method for treating wool, corduroy, denim, and canvas consists of dipping the clothing (after it has been washed and centrifuged) in a 15 per cent solution of either diammonium phosphate or ammonium sulfamate. After saturating the clothing thoroughly in this solution, it is placed in a draining rack and the excess liquid allowed to drain back into the impregnating solution, which is kept in an earthenware crock. The clothing may then be dried directly or centrifuged for one minute and then put through the regular drying process. Clothing so treated will char, but will not flame when it comes into contact with molten magnesium or flux. The ammonium sufamate is less irritating to sensitive skin.

Methods of extinguishing magnesium fires have been dealt with in a number of publications and will not be considered here.

IV. Sizes and Tolerances

The limitation on maximum size of castings will be dependent, of course, on the equipment available. As has been stated previously, the size of a casting which may be made on a given piece of equipment is related to the projected area of that casting and the injection pressure required to produce a satisfactory product.

While wall thicknesses as low as 0.040 in. have been successfully cast, the more practical minimum is about 0.050 in. It has been suggested[1] that an approximate rule for wall thickness up to 0.130 in. has been 1/1000 of the surface area; thus, the minimum thickness for an area of 100 sq. in. would be 0.100 in. Numerous exceptions to this rule occur due to the casting design and the relations of the area in question to the gates.

The following tolerances generally apply to magnesium die castings:

	Inches
Tolerance per in. of dimension	±0.0015
Minimum tolerance within solid die	±0.003
Minimum tolerance across parting line or between solid die and movable die parts	±0.005

V. Machining and Finishing

Not too much consideration will be given to this subject, since die casters usually furnish the parts as cast with either the original surface or, perhaps, a chemical treatment for protection during storage.

The finishing of magnesium alloy die castings presents few problems, the methods used for other metals generally being applicable with little modification. Machining is easily accomplished, usually dry, but with an oil type coolant for high-speed operations if very accurate dimensions must be maintained. For extreme accuracy of parts, it may be desirable to stress relieve the die castings by heating for 2 to 4 hr. at about 400° F. before machining. Such a treatment also results in a stabilization of the alloy constituents such that a negligible amount of growth would take place if the casting is to be subjected to elevated temperature use. Unit growth for magnesium die castings is as follows:

	Inches
As die cast	0.00033
As cast and stabilized	0.00016

As has been previously stated, scrap from casting and machining operations should not be remelted for die casting directly, but instead should be refined in a separate pot, also described previously.

The chemical treatment usually applied by die casting producers is the chrome-pickle treatment, or perhaps, in some cases, the fluoride-dichromate treatment. Since details of these processes are covered elsewhere, no discusison will be given.

Reference

Winston, A. W., *"Magnesium Alloy Die Castings,"* PROCEEDINGS, A.S.T.M., vol. 39, pp. 284-296 (1939).

GAMMA RAY RADIOGRAPHY

Its Advantages and Disadvantages

By R. A. Gezelius, Chief Metallurgist,

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• Radiographic inspection is among the tools employed by the foundryman to evaluate his product and to assure its perfection. The rigid specifications and high acceptance standards for wartime products—which the foundryman has met successfully—will be demanded for postwar products, and the foundryman has available the tools to meet these demands.

THE subject of non-destructive testing of castings has received considerable attention in recent years, and no doubt will receive even more in the future. In fact, the increasingly more rigid specifications for castings will guarantee an increasing interest. These more rigid specifications will lead to the production of better castings, free from internal defects.

There is no doubt that specification requirements will be more strict as time goes on. During the present war, the War and Navy Departments have converted many forged parts to castings in order to utilize the full productive capacity of the country. These converted parts have been studied carefully. The standards of acceptance have been high. However, the foundry industry has been able to produce the required material.

Rigid Specifications

Many of the articles which have been produced as castings for the war effort are in the "restricted" class and, therefore, the specifications employed and the results obtained have not become common knowledge. However, it is only a question of time until the armed services will demand the same degree of perfection in all castings produced for them.

Commercial purchasers will then, in turn, demand comparable castings for their use. In view of these facts, it is now more important than ever that foundrymen employ the non-destructive tests available to them as tools to evaluate and perfect their own product.

One of the non-destructive tests which is available to foundrymen is radiography by the use of gamma rays. Mehl, Doan and Barrett,* in 1930, showed the possible use of gamma rays for the detection of defects in metals. Since that time many papers have been published, in which every phase of the techniques of making, developing and interpreting radiographs has been discussed.

Radiographic Process

In addition, standards of acceptance for various items have been prepared and are in use by at least two government agencies. Some commercial consumers also use these standards, or variations of them, as their standards of acceptance. These data are all available in the technical literature, so there is no point in reviewing the information here.

For the purposes of this discussion, the radiographic process can be simply explained as the production of shadowgraphs which indicate the comparative densities of various portions of the article being examined. The entire process can be visualized by comparing it to the production of a print from an ordinary photographic negative, a process familiar to everyone.

For this purpose, we may assume that the photographic negative is the part to be examined. On this negative the clear areas will represent actual voids, the light gray areas will represent areas of low density such as sand or slag inclusions or porous or spongy areas, the darker gray areas will represent solid metal and the black areas protrusions on the casting.

In the photographic printing process, the negative is placed adjacent to a piece of sensitized photographic paper, between the paper and a source of light. The light rays pass through the negative and are recorded on the sensitized paper. The sensitized paper will be blackened in varying degrees, depending upon the amount of light absorbed by various areas.

Photographic Prints

The areas adjacent to clear areas on the film will be very black, as the negative has permitted all light to pass at this point. The areas adjacent to dark areas on the negative will be very light in color, as the negative has permitted little or no light to pass at this point. This process is identical with the radiographic process except that in radiography the light source is short wave length invisible light such as x-rays or gamma rays.

These light rays are absorbed by a metal mass of varying density, and the sensitized paper is replaced by a sensitized radiographic film. The result, in radiography, is a

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*R. F. Mehl, G. E. Doan, and C. S. Barrett, "Radiography by the Use of Gamma Rays," *Transactions*, American Society for Steel Treating, vol. 18, p. 1192 (1930).

shadowgraph which indicates the comparative densities of the part inspected by the degree of blackening obtained on the film.

As the interest in radiography has increased, more attention has been paid to the advantages or disadvantages of x-ray and gamma ray inspection. There have been many discussions which have attempted to indicate that one of these sources of radiation is definitely superior to the other. This attitude has led to considerable confusion, as each of these sources of radiation had advantages and disadvantages not possessed by the other.

Inspection Method Selection

Each of these methods of radiography has certain fields of inspection for which it is definitely superior. There is, of course, some overlapping of these fields of inspection, but the two methods of inspection should be considered as complementing each other rather than as competitors.

Radiography, whether conducted by x-rays or gamma rays, has a decided advantage as a method of inspection in that it is possible to determine the degree of soundness of a casting without destroying the casting itself. This is extremely important in the production of large castings, where tests by destruction would be both expensive and time consuming. On castings of these types, the method can be also used to prove the acceptability of any welding repairs which may be required as a result of either visual or radiographic inspection.

While radiography has decided advantages as an inspection medium, it also has its limitations and cannot be relied upon to disclose every defect in the part examined. The difference in density between a sound area and an area containing a defect must be sufficiently great to cause a change in the degree of blackening on film sufficient to be noted by the eye.

The change in density required for this will depend upon the density and thickness of the material inspected, the wave length of the radiation used and the technique employed. On thin sections of the light alloys, extremely small defects may be located with long wave length radiation. However, on steel, bronze or the other heavier alloys, with the shorter wave lengths required to penetrate this material, a change in density of 1½ to 2 per cent is required.

Thus, a single defect with a dimension of less than 1½ to 2 per cent of the total thickness of the piece being examined will not be disclosed. All defects with dimensions greater than this will be revealed. It is obvious that radiography cannot be expected to disclose fine cracks, for example, unless the depth of the crack is in line with the rays passing through the piece.

All of the foregoing applies to radiography generally. Radiography with gamma rays has certain advantages and disadvantages which are peculiar to it. All of these advantages are dependent upon two physical facts; (1) the method by which the rays are produced and (2) the wave length of the rays themselves. These advantages and disadvantages may be tabulated as follows:

Source of Radiation

Advantages
- Portability
- Simplicity of Operation
- Constant Activity

Disadvantages
- Constant Wave Length
- Constant Intensity

Wave Length

Advantages
- Good Penetration
- Less Scattering

Disadvantages
- Less Contrast
- Slower Speed

These advantages and disadvantages will be discussed in detail in the following paragraphs.

Radiation Source

X-rays are a man-made source of radiation and, therefore, a wide choice of wave lengths and intensities are available in the initial choice of equipment. Each particular x-ray is limited in wave length variations, but the intensity of the ray may be varied considerably.

Gamma rays are a product of nature. They are produced by the dissociation of radium. Radium decomposes at a constant rate into the gas radium emanation, which, in turn, produces a series of decomposing solids, some of which give off gamma rays. Radium is prepared for industrial radiography by placing a known amount of a radium salt in an hermetically sealed silver container.

The radium salt placed in this container decomposes, forming radium emanation which builds up until equilibrium is reached, when the rate of decay is equal to the rate of formation. After equilibrium has been attained, the strength, or intensity, of the radiation given off is proportional to the amount of radium present.

The wave length of gamma rays cannot be varied, as is the case with x-rays. The intensity can be varied only by increasing or decreasing the amount of radium present in the sealed cylinder. The intensities available in these sealed cylinders vary from those which contain 25 milligrams of radium to those which contain as much as 500 milligrams.

Gamma Ray Emission

The 25-milligram capsule is a sphere approximately 3 millimeters in diameter. The largest capsules are cylinders approximately 10 millimeters in diameter and 7 millimeters high. In industrial work, these small silver capsules are protected from damage by being enclosed in an aluminum "egg" to which cords are attached to facilitate handling.

The decomposition of radium is a continuous process. Gamma rays are thus emitted continuously. When not in use the capsule is usually stored in a portable lead-lined case, which absorbs most of the gamma rays produced. The material may be transported safely in these lead-lined cases, which are supplied with the radium pellet.

The small size of the radium pellets leads to one of the principal advantages of gamma-ray radiography, portability. The source of radiation in its lead-lined container is sufficiently small and light to be transported readily to any piece which is to be inspected.

In addition, the source of radiation is itself so small that it can be attached to the end of a rod and inserted in a narrow opening, or pulled into place by the cords attached to its aluminum container.

This extremely portable source of radiation has permitted radiographic examinations of many articles which could not be inspected by any other method. For instance, the sternpost of a ship has been radiographed while the ship was moored to its pier.

Inspection was carried out by tack welding a tripod support to the outside of the sternpost to sup-

port the radium capsule. The films were placed on the inside of the sternpost. The source of radiation, the sternpost and the films were thus always in the same relative position and not affected by the rolling of the ship.

The ship was in port for only a few days and, as the proper type of electric power was not available, this casting could not have been inspected with x-rays within the time allotted, even if the proper support for the x-ray equipment were attached to the side of the ship.

Large Casting Inspection

In the larger jobbing foundries, there are many large castings which can be inspected easily with gamma rays, without positioning, which would be difficult to handle with x-ray equipment.

The ease of manipulating the source of radiation itself has permitted the examination of enclosed box sections, deep pockets in castings, the joints in long lengths of welded pipe, etc., many of which cannot be reached with an x-ray tube and are too small or too difficult to reach for the proper placement of films on the inside of the section.

Another advantage of gamma ray radiography associated with the method by which the rays are produced is the simplicity of conducting gamma ray inspections. A definite intensity of radiation is always available with each radium capsule. The operator merely has to place the pellet and film in their proper locations and time the exposure correctly.

Timing Exposure

Slide rules and charts are available to assist one in these simple calculations. As the source of radiation is continuous, the exposure may be adjusted to run overnight or over the week-end by a proper selection of the film-to-source distance. It is not necessary for an operator to be present to watch or control the process of radiographic inspection.

The principal disadvantage of gamma ray radiography, due to the manner in which the rays are produced, is the inability to change the wave length of the radiation produced. The wave lengths of gamma rays are comparatively short, and are considered comparable to those which would be produced by a two and one-half million x-ray tube.

The wave length of the radiation employed in radiography has a large bearing upon the results obtained. Long wave length x-rays, which are produced in x-ray tubes with a comparatively low potential, are easily absorbed by solid masses. They, therefore, cannot penetrate great thicknesses or material of a high density. However, they are easily recorded on a photographic film.

This ease of recording, plus the fact that a slight change in density will cause a comparatively large change in the amount of radiation absorbed while the ray is passing through the piece being inspected, results in extremely good contrast in the radiograph obtained. On light alloys and thin sections, the best results are obtained with equipment of this type.

All radiation passing through a test piece creates within the piece secondary radiation of a wave length longer than that of the primary ray. This is known as "scattering." This secondary or scattered radiation is also recorded by the photographic film. As the scattered radiation has a longer wave length than the primary ray, it is recorded by the film even more readily than is the primary ray.

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Steel Division of A.F.A.

As the thickness of the test piece increases, the amount of the primary ray reaching the film decreases, but the amount of the secondary radiation increases until the secondary radiation will cover over any image produced by the primary ray unless special precautions are taken. Therefore, as the density or the thickness of the material to be radiographed increases, it is necessary to use rays of greater penetrating power to decrease the difficulties due to scattering.

Greater penetrating power is obtained by using rays with shorter wave lengths which, fortunately, scatter less. The secondary radiation produced also has a shorter wave length, and thus difficulties due to scattering are decreased.

As the wave length of the ray is decreased, the ease with which the rays are recorded on the film is also decreased. The change in the amount of radiation absorbed by slight changes in density is not as great as with longer wave lengths, and thus, while difficulties due to scattering are reduced, the contrast of the finished negative is also reduced.

As the wave lengths of gamma rays cannot be changed, and they are comparatively short, they are not suitable for all types of radiography. They are not as satisfactory for thin sections or for light alloys as are the longer wave length x-rays. Good results are obtained on the heavier alloys in sections of over ½-in. thickness.

The short wave length of gamma rays reduces the difficulties due to scattering to the point where artificial methods of control are not required. However, there is some loss in contrast, and this should be considered when comparing radiographs produced with gamma rays and with x-rays of longer wave length. In addition, these short wave length gamma rays have excellent penetrating ability, and can be used to radiograph sections which can be penetrated only by the largest x-ray machines.

Radiation Intensity

The intensity of the radiation produced by radium is not as great as that produced artificially by the x-ray tube. Gamma ray radiography is, therefore, slower than radiography with x-rays when the time required to produce one radiograph is considered.

Gamma rays are emitted from the capsule in all directions, and many times it is possible to produce several radiographs simultaneously. In these cases, the overall time required to radiograph an entire object, or several objects, may compare very favorably with that required when x-rays are used.

Gamma ray radiography has an additional advantage for jobbing foundries which employ radiography only occasionally. Radium capsules of various sizes are available on a rental basis. Gamma ray inspections can, therefore, be conducted without large capital expenditures.

Sand Control in a
MALLEABLE IRON FOUNDRY

• This paper on malleable foundry sand control is one of several being prepared at the request of the Malleable Division Program Committee, which is planning to continue the yearly symposia on malleable foundry practice started several years ago. These papers on this subject will later be incorporated in a reprint on malleable sand control as the Division's contribution to the 1945 program. Included in this symposium will be the summary of some 14 companies' answers to a questionnaire on malleable sand control.

The ultimate objective of the Division is to later incorporate all of these symposia in a book on malleable foundry practice. Previous symposia covered (1) Graphitization of White Cast Iron, (2) Malleable Iron Melting, and (3) Gating and Heading.

By Gordon Davis, Assistant Superintendent,

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International Harvester Co., Chicago

PROPER molding sand in a malleable foundry is one of the most important items in the production of good castings. For various types of castings, satisfactory and consistent production is almost impossible without a sand control standard.

Sand control becomes a necessity because of inspection requirements of high quality finish, and in the interests of cost reduction to eliminate finishing operations on rough castings and to simplify sand control for individual molders.

Work which has been done to develop and perfect sand testing has really taken a burden from the foundryman's mind by helping in the elimination of superficial cracks, internal shrinkage, etc. It has resulted in improved cleaning methods and a much desired surface finish.

The men connected with the early development of sand control really belong in our "Hall of Fame." With the old hand control method of trial and error many castings were made but, as in all other lines of manufacturing, scientific control and continued research makes mass production possible today. The "practical foundryman" and the daily reports on the condition of his sand are a team much like the melter and his regular reports of the metal composition.

The advantages of sand control have been demonstrated on castings of simple design, with good gating and feeding methods, and proved many times by the use of the right and wrong sands. Sands, with moisture, permeability and bond properly controlled, can give castings free from hot tears, cracks and sand defects, while a sand with a high moisture content, with low permeability and high bond may show castings with defects such as scabs, hot tears and rough finish.

Different Sands Used

In the production of large quantities of various sized castings used for light and heavy duty trucks, tractors, agricultural implements and ordnance vehicles, several different heap and facing sand mixtures are used.

Many agricultural castings when annealed, cleaned and straightened are used in the "as-cast" condition one casting working into another and held to close tolerances for foundry fits, that is, fits which must be satisfactory without machining. This is very general in chain links, roller bearing ends, and other small castings. The manufacturing tolerances are plus or minus 0.006 in. on chain links and plus or minus 0.007 in. on roller bearing ends.

Sand Conditioning Equipment

To keep the sand heaps in condition four gasoline motor driven sand cutters are used. These sand cutters handle the majority of the sand used in the foundry. Heaps are cut twice daily after the heats are poured, and by proper cutting good mixing and aerating are obtained. The second cutting is made immediately after the first heat.

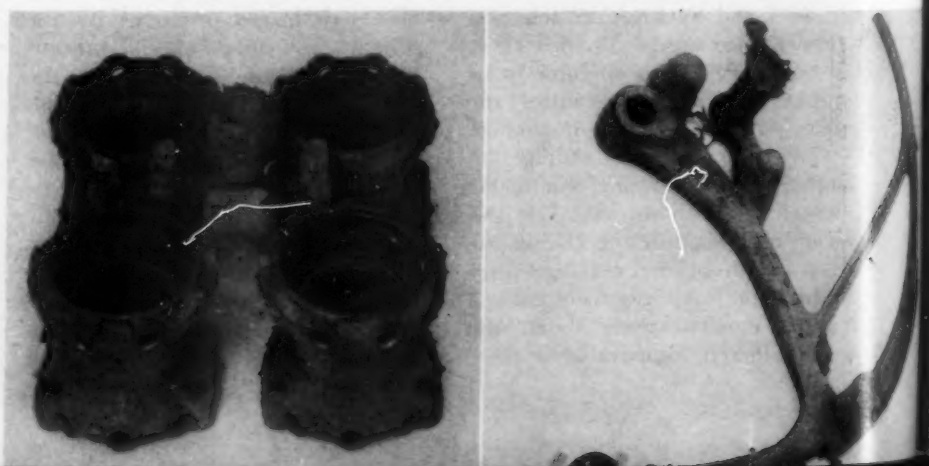
Six portable sand-conditioning units are used on the large molding machine floors. These machines give a well mixed and well aerated sand in addition to removing tramp iron, chills and core butts. They require more manpower to operate than does a sand cutter.

Sands for Light Castings

A sandslinger is used as a sand conditioner and as a molding unit. This piece of equipment is very efficient both as a sand conditioner and a mold producing unit. Three intensive mullers furnish sufficient facing sand for the daily requirements.

On floors where the smaller castings such as chain links, roller bearing ends, knife clips, etc., are made, frequent additions of ground rock sand (4-6 per cent A.F.A. clay content, 240 fineness and 16-20 permeability at 5 per cent moisture) are made. Sands with a good flowability are required for this type of work

Examples of medium sized malleable castings showing gating method.



in order to meet the exacting inspection requirements for finish and dimensions (Table 1).

These small castings require special finishes, are closely inspected, and sands of a lower bond which have less tendency to burn on are used. No sea coals or dust-on facing materials are used on these light castings to improve the finishes. It has been the experience in this plant that sea coal and dust-on facings tend to cause hot cracks on castings of intricate design.

Sands for Medium Size Castings

The physical properties of individual heaps for squeezer machines on medium sized castings are kept in condition by adding a natural-bonded sand. This is a sand with an 11-13 per cent A.F.A. clay content, with a 200 fineness and a 25 permeability at 6 per cent moisture (Table 2). This is added on the heap before the sand is cut to get the most effective results.

Sand heaps for producing medium sized castings may retain a considerable amount of core sand from the shakeout, and the permeability generally is much higher than that of the new sand. There will also be a considerable amount of facing sands used in these heaps, which would tend to keep up the bond to a sufficient extent.

Again, there may be sufficient permeability so that a mulled bond could be added to the heap before cutting, as well as some new lake sand. Many heaps used for medium sized castings may require from 10 to 20 cu. ft. of facing sand to obtain the required finish. This may be as much as 10 per cent of the sand on the floor.

Sands for Heavy Castings

Sands used on heaps making the heavier castings on large jolt machines generally have a higher permeability due to a larger volume of retained core sand (Table 3). The physical properties of these heaps are kept up to molding sand requirements by frequent additions of natural bonded sand or a mixture of colloidal clay mulled with new lake sand.

Closely controlled facing sands used on the heavy castings have small quantities of a coarse grade of sea coal. The facing sands also help to keep the sand open and the green

Table 1

Daily Sand Tests for Light Work

	Chain Links			*Roller Bearing Ends*		
	Heap Sand			*Heap Sand*		
Sample No.	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*
1	6.2	37	4.6	4.8	20	5.4
2	6.4	45	3.9	6.6	24	4.5
3	6.0	42	4.2	6.2	31	3.8
4	6.0	38	4.3	7.4	35	3.8
5	5.8	47	3.9	6.6	33	3.5
6	5.6	42	3.5	6.4	27	3.6

Table 2

Daily Sand Tests for Medium Work

	Heap Sand			*Facing Sand*		
Sample No.	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*
1	5.6	90	4.9	3.6	165	9.8
2	6.0	100	5.4	3.8	160	10.3
3	5.2	100	4.7	3.6	165	9.2
4	5.2	90	6.3	4.2	150	9.4
5	4.8	95	5.8	3.6	180	11.0
6	5.0	105	5.5	3.6	175	8.5
7	5.2	90	4.6	3.8	180	8.3
* 8	4.4	135	6.0	3.5	170	8.1
* 9	4.8	135	5.3	3.6	130	10.7
* 10	4.2	130	6.9	3.8	135	11.2
* 11	3.7	130	8.1	3.5	145	10.3
12	3.9	140	6.7	3.9	140	9.9

*These are samples from sand heaps and facings that are used to make castings of a special design which are very prone to crack and which require special finishes.

Table 3

Daily Sand Tests for Heavy Work

	Heap Sand			*Facing Sand*		
Sample No.	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*
1	4.2	170	8.2	4.0	170	11.8
2	3.9	165	5.7	4.2	160	10.9
3	4.0	180	6.4	3.8	175	11.3
4	4.2	160	6.0	3.8	170	11.7
5	4.2	160	4.5	3.8	185	9.5
6	4.1	175	4.7	3.6	150	9.9
7	4.0	155	5.8	4.0	170	10.5
8	4.0	155	6.6	3.9	175	10.2
9	3.6	175	7.2	3.8	165	11.6
10	4.6	170	5.4	4.1	170	10.7

Table 4

Daily Sand Tests for Truck Wheels

	Heap Sand			*Facing Sand*		
Sample No.	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*	*Moisture, per cent*	*Permeability*	*Green Strength, psi.*
1	4.0	145	4.8	3.2	170	10.8
2	3.6	150	5.1	3.3	165	10.8
3	4.1	140	4.2	3.2	170	11.1
4	3.6	140	5.9	3.4	180	10.4
5	3.8	145	5.5	3.3	185	9.7
6	3.6	150	5.7	3.4	180	10.5
7	3.8	150	5.3	3.3	185	10.6
8	3.4	145	5.6	3.3	180	10.2
9	3.6	145	5.9	3.4	180	10.5
10	3.4	150	5.2	3.4	185	10.1
11	3.8	155	4.3	3.3	185	9.7
12	3.4	155	5.6	3.4	180	9.6

Table 5

FACING SAND MIXTURES

Light Castings	*Medium Castings (Regular)*	*Medium Castings (Open)*
24 parts Heap Sand	30 parts Heap Sand	20 parts Heap Sand
12 parts New Molding Sand	10 parts New Lake Sand	20 parts New Lake Sand
4 parts New Lake Sand	3 parts Clay Bond	2½ parts Clay Bond
	(2 parts of sea coal are added only when required)	4 parts New Molding Sand

Heavy Castings (Regular)	*Truck Wheels*
20 parts Heap Sand	20 parts Heap Sand
20 parts New Lake Sand	20 parts New Lake Sand
3 parts Clay Bond	3½ parts Clay Bond
2½ parts Sea Coal	2½ parts Sea Coal

strength up to standard.

The sand from the slinger floor used in molding truck wheels is checked each hour. Samples are taken after passing through the head, as it is found that permeability is somewhat reduced through the head. On this floor only synthetic sands are used. Rebonding is done with a mixture of 10 parts of colloidal clay and 40 parts of new lake sand mixed in a muller. Enough is added each day to maintain predetermined standards by additions on molds before shakeout (Table 4).

Sea Coal Added

Facing sand with sea coal additions for truck wheel castings is used on the cope side of patterns only as a means of lifting the deep pockets. Rigid standards are used on truck wheel facing sand as it must have just sufficient green strength to lift the mentioned pockets.

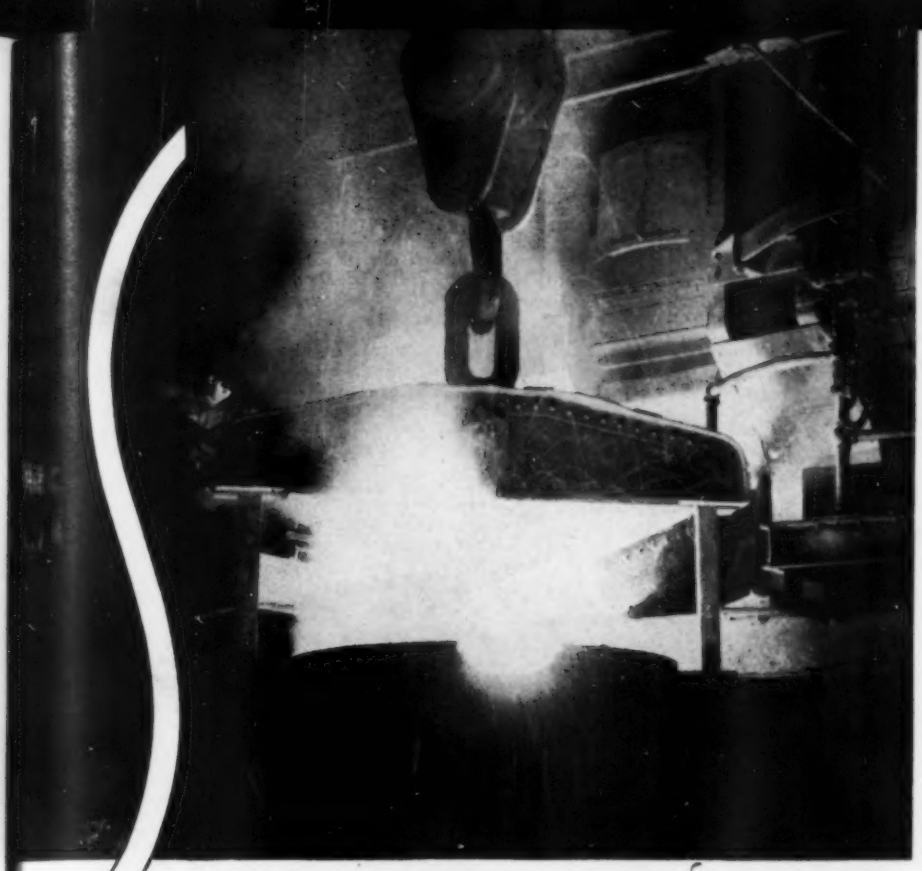
Moisture is kept low so as not to bake too hard for easy contraction of castings. This particular job is susceptible to hot cracks unless all involved materials are at the highest possible workable standards.

The tests shown in Tables 3 and 4 are made on samples from different floors, some of which require a higher green strength than others depending upon the size and shape of the flask and the nature of the casting in production.

Facing sand mixtures are varied according to the size and requirements of the castings. On some fairly heavy castings it has been found desirable to have a more open facing. Typical examples of the mixtures used for the various facings are shown in Table 5.

Each foreman and his assistants have a particular class of work for which they must choose the sands and the facing which are best suited to the requirements of the casting. The right sand for each specific casting is not enough. It is the day-to-day uniformity, which is maintained by frequent testing and regular adjustments, that counts in the long run for quality production.

It is the purpose of this paper primarily to record the details of the sand control practice used in this foundry. It is the faithful adherence to control that results in a better casting and more satisfactory production.



STEEL FOR CASTINGS

. . . Methods of Production

A Report of the Steel Division Committee of A.F.A.

• Developments and trends in methods of producing steel for castings is reported to the members of A.F.A. Steel Division; some of the problems of current concern to steel founders—hardenability, grain size control, graphitization — are discussed briefly. An extensive bibliography of recent publications is appended.

DESPITE the exigencies and abstraction of a full-time schedule of war production, there seems to be steady progress in the methods of producing steel and in the quality of steel for castings. Problems imposed by the poor quality and heterogenious nature of available steel scrap have been fairly satisfactorily overcome.

It has been shown by Zang[12] how purchased alloy scrap may be used successfully up to 40 per cent of an electric furnace charge. By means of proper segregation and sampling methods, it is possible to use this amount of alloy scrap with a substantial saving in ferroalloy requirements and yet meet all current specifications as to properties.

In a prediction that electric furnace steel will compete directly with open-hearth steel in the postwar period, Sisco[25] concludes that basic electric steel can be made at a cost of $2.00 to $4.00 per ton above that for basic open-hearth steel, using a cold charge.

The quick immersion thermocouple[7] of the platinum/platinum-rhodium type, protected with a thin sheath of fused silica, is being used very successfully for measuring temperatures of molten steel. It requires from 10 to 20 seconds for a reading. The silica protection tube is good for a maximum of about six immersions, although, in practice, it is usually replaced after each reading.

One laboratory reports good accuracy in measuring temperature of molten steel by immersing a closed end silica tube in the bath and sighting down it with an optical pyrometer. This arrangement provides black body conditions free of smoke or fume, and it is claimed to be lower in cost than the thermocouple method.

Slag control, particularly for acid slags, is receiving considerable attention. Fitterer[33] reported that it is now possible to determine both the silica content and temperature of an acid open-hearth slag by means of a simple fluidity test. Furthermore, because the MnO is practically a constant, the FeO + CaO is then known, and if the CaO is a controlled quantity, the FeO content may be determined. He also proposed a new and interesting theory that oxidation of the bath by atmosphere is through direct exposure of the metal during the boil rather than through the slag as an intermediate.

Side-Blown Converters

In Great Britain, a much larger proportion of steel for castings is produced in side-blown converters than in the United States. Fassotte[27] has shown that, contrary to common belief, a high-silicon iron charge is not necessary when a side-blown converter is used. Whereas, in the bottom-blown converter, the product of carbon combustion is mainly CO, in the side-blown converter it is burned largely to CO_2. Thus, an important source of heat energy is available to the latter, which obviates the necessity of burning silicon if the initial temperature of the iron is sufficiently high.

A charge containing 3.2 per cent of carbon and 0.21 per cent of silicon was introduced to a converter at a temperature of 1385°C. (2525°F.) and successfully blown with a final temperature of 1590°C. (2895°F.). A rotary, pulverized-coal-fired furnace to act as a preheater and mixer is advocated for use between the cupola and the converter when low-silicon irons are used.

Thermit Method

The thermit method of producing steel for small castings has been completely successful in experiments carried out at the Naval Research Laboratory. Steels with very normal properties were obtained. This method is considered primarily for emergency use where small castings are needed quickly in areas remote

from orthodox melting equipment.

Precision casting of many metals and alloys is presently undergoing intensive development. In preparing steel for these castings, indirect arc and high-frequency induction furnaces are preferred. An extensive line of melting units of these types, specially designed for precision casting, are being offered by various manufacturers. At least one small direct arc furnace is available.

Among the newer problems that are currently of concern to the steel founders are those of hardenability, grain size control, and graphitization. To a certain extent, these problems are interrelated and are problems of steelmaking technique.

Hardenability

Controlled hardenability for castings is increasingly in demand with the greater prevalence of quenching treatments. The problem is complex, because, with the variable section size both in single castings and in different castings from the same heat, no one hardenability level is ideal. Experience indicates that reliance on close chemical composition is not a sufficient control and that a direct hardenability test should be made on each heat.

This means segregation of heats for heat treatment. The ideal way, of course, would be to make a quick hardenability test before the heat is poured, and then make appropriate adjustments to the composition.

Grain Size

Controlled grain size as an adjunct to hardenability is important, but fine grain is specified for some cast parts which are to be carburized and quenched from the carburizing pot. The problem of obtaining fine grain is that of adding the proper excess of strong deoxidizer and, when aluminum is used, requires the same technique as is used to insure Type 3 inclusions for good ductility.

For certain uses, however, particularly for high-temperature service, coarse-grained steel is demanded. This has become a serious problem where the use of aluminum deoxidation is considered necessary to obtain the required soundness.

Graphitization

Of even greater current importance is the demand that steel castings for use in high temperature be made aluminum free to prevent graphitization. It has been found in weldments (both wrought and cast) used at high temperature, that graphitization starts in the heat-affected zone after prolonged exposure. This results in serious embrittlement. It has been shown that the rate of graphitization is increased when aluminum is used, unless it is used in such small amounts that it is all oxidized. Apparently no adequate answer to this problem has yet been found, but considerable experimental work is under way. A quick answer is not probable, however, because of the time required for tests.

COMMITTEE ON METHODS OF PRODUCING STEEL FOR CASTINGS

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CASTINGS *Should Always Be* QUALIFIED *in the Foundry*

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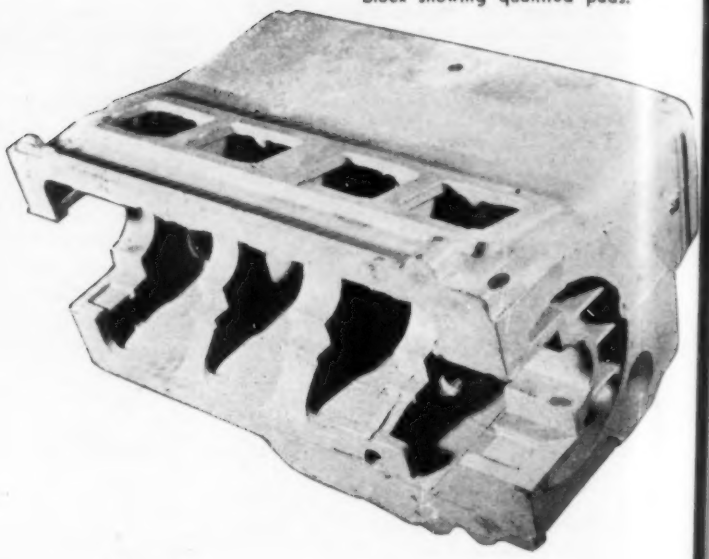


Fig. 1 — Cast four-cylinder diesel engine block showing qualified pads.

• *Methods of casting qualification in the foundry to reduce machine tool costs and facilitate machining are presented by the author, a particular point being the use of less highly skilled operators.*

IN THE early 1920's, the demand for more production forced manufacturers to try to devise some ufacturers to try to devise some method of control of given points on castings. If parts could be produced uniformly enough in the foundry, the machining was fairly simple. However, with castings that had too much distortion, exterior roughness and uneven parting lines, targets had to be added to the first machining operation fixtures, with adjusting screws to juggle the casting around to equalize the distortion between the faces to be machined. This was a slow process, requiring care, and resulted in idle time for expensive machinery with a consequent loss of much production, but it could be accomplished by skilled operators.

Locating Bosses

The first attempt to better this condition, to the writer's knowledge, was the establishing of bosses on the casting which were hand filed by the manufacturers[1,2]. In filing, the casting was placed in a fixture fitted with a series of adjusting screws. The casting then was moved until it matched with targets on the fixture, which were of the same contour as the faces to be machined. The pads then were hand filed until level with blocks on the fixture set at a predetermined height. This was not entirely satisfactory, as in filing the pads usually were not square and there was not close enough dimensional control. The method was slow and, consequently, expensive.

The present-day methods are the grinding or machining of bosses, the number and location being the result of a study of the part involved for subsequent machining. Usually, three bosses are required on the casting face which is to be the bottom in the first machining set-up. These three bosses furnish a three-point leveling condition for horizontal and vertical planes. Two bosses at the extreme end of a side face insure squareness of location in the fixture, and one boss at the extreme end provides an end locating point.

An example of such preparation is the cast block for a four-cylinder diesel engine, shown in Fig. 1. In this case, the three bosses are on the side of the block, which is the bottom side for the first machining operation. The end boss, in this case, has no function in the first machining operation, but is used in locating the casting for a succeeding operation, in which the flywheel housing and timing-gear housing faces are to be milled.

Fig. 2—Qualifying grinding fixture.

In checking this casting at the foundry, it is placed in a fixture with adjusting screws, and juggled to match a series of fixed templets. The points checked include faces, contours, bores and close interference points.

Grinding and Milling

After the casting has been checked and clamped into position, location bosses are carefully ground with a portable hand grinder until sweep gages show that they are correct, as shown in Fig. 2.

When milling locating spots, much the same treatment is applied to the casting as in grinding. In qualifying fixtures where the spots are to be machined, the casting is supported on adjusting screws to position it with relation to the targets. Shaped targets or templets made from cold-finished sheet steel are employed, for checking the size, shape and location of various bosses and other surfaces. These targets can be mounted either in fixed positions or on sliding support arms, which can be withdrawn to permit clearance to

This paper was secured as part of the Program for the 1945 "Year-'Round Foundry Congress" and will appear in an "Inspectors Manual" to be published by your Association. Suggestions for the "Manual" will be appreciated by the Inspection of Castings Committee of A.F.A.

facilitate loading and unloading of the part. Care must be exercised in the design of these fixtures to provide as much visibility of the work as possible.

Many times, flush pins and scribes are used to determine the amount of stock to be removed for clean up. (Fig. 3.)

After the casting has been put in alignment, it is then clamped securely in place. The casting is now ready for milling, which is done with a special stop-collar holder, using a four-fluted end mill, cutting off center in order to eliminate tool pressure. A suitable air motor is supplied, with the correct rpm., and may be provided with an overhead harness for easy handling. The cutter holder is inserted in a hardened steel bushing on the fixture, a cutter inserted in the end of the spindle and held in place with a tie-bolt, then the cutter is rotated until the pad is milled, as shown in Fig. 4. The spot then can be checked by means of a flush-pin gage, made with the amount of allowable tolerance.

A ball-thrust bearing race contacts the shoulder of the counterbore in the head of the holder, which permits about a 3/16-in. stroke. Since the stock to be milled is about 1/16-in. thick, the locknuts are in contact with the head of the guide bushing throughout the milling operation. Locknuts are positioned on the sleeve of the driver when the driver is set up in a special gage developed for this purpose, as shown in Fig. 5.

Standardization

When contemplating having several different castings qualified in the same foundry, care should be given to standardization. All the equipment that would possibly be needed, other than the basic fixture and air motor, is shown in Fig. 5; namely, a cutter setting gage, driver, holder, flush-pin gage, and several cutters, which should be kept sharp by the vendor, who has the facilities.

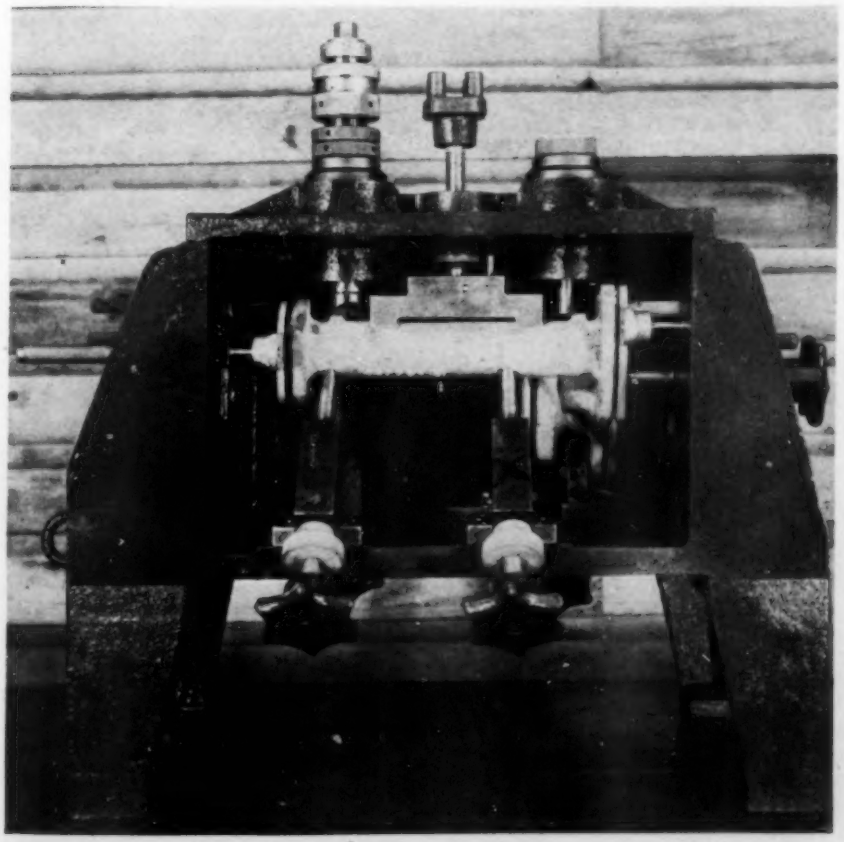
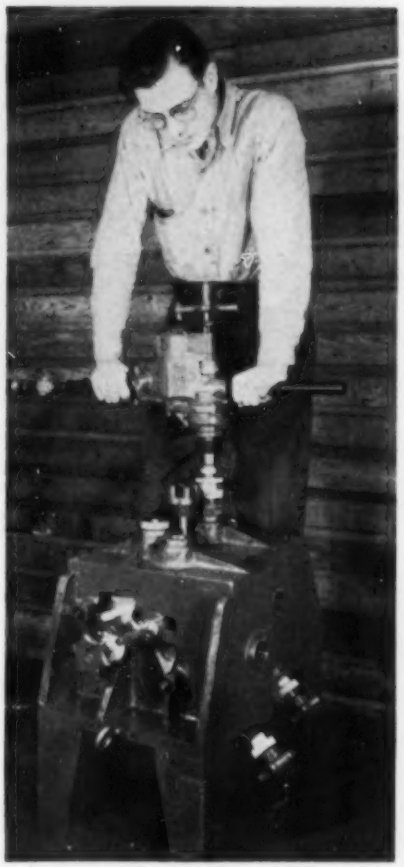


Fig. 3—Foundry qualifying fixture with casting in place.

Fig. 4—Application of milling on casting shown in Fig. 3.



Gray Iron Castings

It has always been thought that this method would not be acceptable on cast iron, having been used only on non-ferrous castings. This is entirely erroneous, as the casting shown in Fig. 6 is of cast iron. Note the front boss located at the top which was entirely removed to check the machining time and the amount of tool pressure required. This boss was originally ¼ in. in height and was removed in about 90 seconds with the equipment shown in Fig. 4, with no undue tool pressure. Normally, the amount of stock to be removed would be between 1/16 and ⅛ of an inch.

The gray iron casting, shown in Fig. 6, was not qualified, due to foundry scrap, but purely for manufacturing purposes. In this particular job, bores on opposite ends, done in two different machining operations, had to be held concentric to

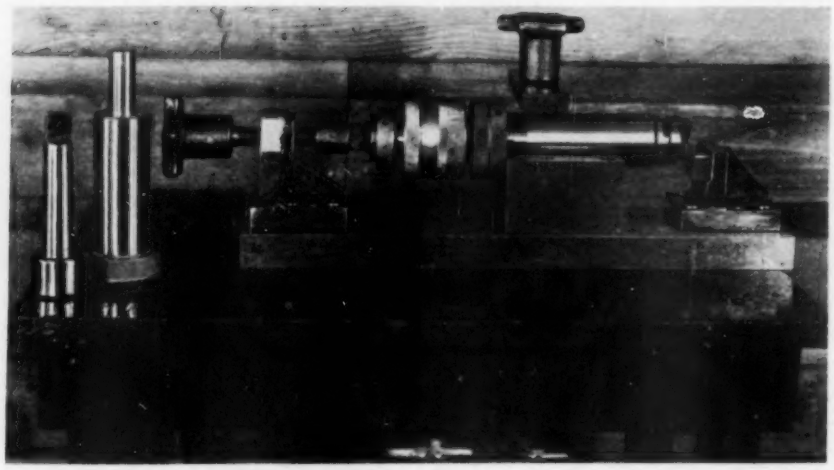


Fig. 5—Cutter-setting gage with holder in position; also, flush-pin gage and driver.

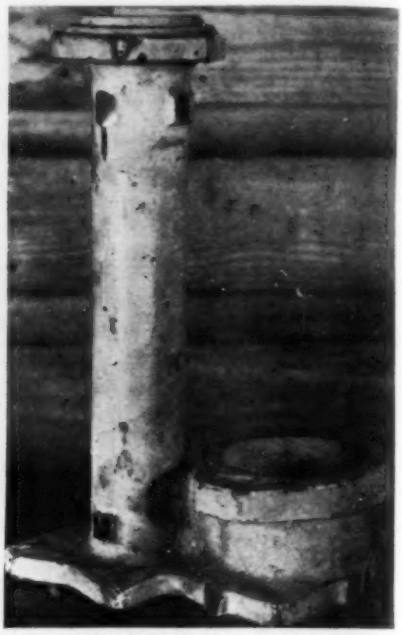


Fig. 6—Gray iron casting showing machined locating pads.

within 0.001 of an inch. It was impossible to chuck on a rough outside diameter and hold these limits. By locating on these finished spots, the seemingly impossible can be accomplished.

The use of prepared castings, with the routine inspection at the foundry, gives an opportunity for the foundry to find the source of faults, if any, and make corrections with a minimum of scrap and delay. Too, elimination of faulty castings at the source will prevent the waste of machining time on castings that will not clean up, and also will avoid payment of shipping charges on castings that will ultimately become scrap. In all cases, the manufacturer is willing to pay more for castings that have been qualified.

The tool costs of the first operation fixtures are greatly reduced, due to simplicity of fixtures that can be made to run qualified castings, thus eliminating targets and adjusting screws.

Production is greatly increased, thereby cutting the cost of machining. Operators with a lesser degree of skill can be used, and at this time skilled operators are not available.

In every instance, qualifying fixtures have paid for themselves many times over by eliminating the need for laying out castings before machining, and in the reduction of scrap resulting from machining errors on castings because they had not been located properly in the first machining fixtures.

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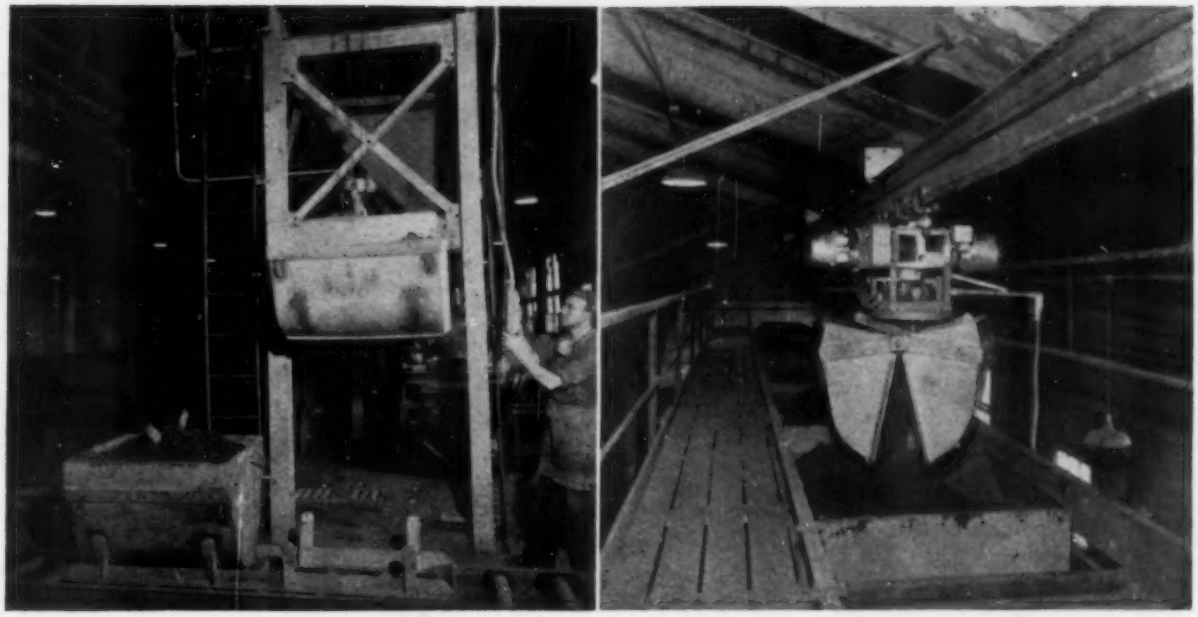


Handling sand in a small foundry can be done easily with modern equipment.

Synthetic Sand in Non-Ferrous Foundries

By N. J. Dunbeck, Vice-President, Eastern Clay Products, Inc., Eifort, Ohio

THE name synthetic sand is usually applied to sands which are made in the foundry as required, from materials so selected as to best do a particular job. Synthetic sands have not been as widely used in non-ferrous as in ferrous foundries for several reasons.

Many non-ferrous foundries are small and lack the mixing equipment which it is desirable to use with all bond clays, and essential to use with some. It is sometimes difficult to locate conveniently the fine grained sands which are necessary for much non-ferrous work.

Synthetic sands usually require closer control than do naturally bonded sands, and some foundrymen feel that they do not have adequate manpower for the job, in consideration of the quantity of sand used.

It is, however, very true that practically all non-ferrous foundrymen can benefit from the intelligent use of bond clays, even though they may not adopt a full synthetic sand program.

Differences Between Synthetic and Naturally Bonded Sands — These sands are similar in that each consists essentially of sand grains and bond. Most naturally bonded sands in Northern and Eastern United States result from glacial action.

Glacial Origin

The glaciers scoured up sand, rocks and clays of various types which were later set free when the glaciers melted. The coarser materials settled from the transporting water first, then the finer sands and, finally, the clay. When the sand in settling carried with it a substantial amount of clay the result was a naturally bonded sand.

It is obvious that the glaciers were not selective in the material picked up, and that this frequently included feldspar, limestone and other materials which have no place in a good sand.

Thus, out of the vast amount of bonded sand in this country, the only usable materials are those where, by happy chance, the glaciers deposited a combination of sand grains and clay which included a minimum of fluxes and other undesirable materials.

The statement is sometimes made that nature took millions of years to make naturally bonded molding sand, with the implication that this must inevitably result in a high quality product.

There is also the suggestion that in this long period of time nature did a perfect job of coating each grain of sand with clay, and that such a job is superior to what may be accomplished by mere man even with the aid of intensive mixing equipment.

The facts are that balls and agglomerations of clay, with perfectly and imperfectly coated grains of sand, are found in practically all naturally bonded sands. Evidence

• Advantages and disadvantages of naturally bonded and synthetic sands in non-ferrous foundry practice. The author concludes that the use of synthetic sands results in lower sand-handling costs and permits of closer sand control than is possible with naturally bonded sands.

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Brass and Bronze Division of A.F.A.

of this is the fact that mulling a new sand almost invariably increases its strength because it better distributes the clay present.

Assuming that the sand producer makes a careful search for sands containing a minimum of undesirable materials, we can assume that a high grade naturally bonded sand will consist of sand grains, clay and silt. The silt is very finely divided material of a silicious nature which has little or no bonding value.

In making a synthetic sand, we seek a good silica-base sand and a good clay to mix with it. Some of the bank sands are also the result of glacial action. To be a good sand they must be quite free of clay, and this requires a condition of deposition from water which permitted the sand to settle while the clay was carried on farther.

The purer silica sands are older than the glacial period, and usually resulted from the decomposition of sandstones which were transported, classified and sometimes purified in running water. High grade clays are deposited in a similar manner, although clays are also formed in other ways.

Synthetic Sand Application

Thus it is seen that the man who proposes to make a synthetic sand has the odds heavily in his favor in making a high grade molding material. He seeks only a pure sand and a pure clay.

In contrast, the producer of naturally bonded sand seeks to find a high grade sand and a high grade clay, not only in combination but also in the proportions he desires and without the inclusion of undesirable minerals.

All such naturally occurring combinations are variable, and it is common practice to mix sands in arriving at a desired product. The difficulty in maintaining uniformity when dealing with so many variables is obvious.

A. Full Synthetic Sand Program —(a) Selection of Sand Grain—In a full synthetic sand program, we plan to make our sand from silica sand and clay. We must locate a silica sand or bank sand of such fineness as to give the finish we require, along with safe permeability.

This new silica sand may be mixed with clay and added in the foundry exactly as is naturally bonded sand; or the sand and clay may be added individually at the shake-out or on the heaps. Sometimes, the materials are added in the facing sand and no additions may then be necessary to system sand or heap sand.

In most synthetic sand programs it is desirable to allow the burned core sand to mix with the used molding sand at the shake-out. The fineness of the core sand thus influences the selection of the base silica sand. If the core sand is rather coarse, a finer base sand may be required, or the reverse.

Synthetic Sand Durability

Burned core sand is an excellent base sand because the somewhat roughened grains accept bond clay readily. The usual procedure is for the non-ferrous foundryman to gradually add synthetic sand to his present sand, making the change a gradual one. In an extreme case, he might discard all of his old sand and start with a new synthetic sand composed of bank sand and bond clay.

The strength of this sand would burn out slowly, as synthetic sands have from three to six times the durability and life of most naturally bonded sands. A very small amount of new material would, therefore, be necessary as a daily addition. The foundryman can expect that his synthetic sand cost per ton of castings will be from one-third to one-sixth the cost of using naturally bonded sands.

(b) Selection of Clay—The choice of clay will usually lie between a fire clay and a bentonite. Each type of clay has definite physical characteristics and produces a notably different type of sand.

Two to three parts of fire clay must be used to give the same green strength as one part of bentonite. This results in definitely lower permeability.

This is a disadvantage when the readily available base sands are fine grained and low in permeability. It may be of advantage when the only available base sands are rather

View of a 25-ton sand storage tank and a 4 cubic foot muller.

coarse, in which case the greater bulk of fire clay smooths the sand and improves the finish.

Fire clays require intensive mixing for dependably good results. They have a wider moisture range than the bentonite and are easier to control. They are more refractory, giving a higher sintering point. They have longer life or durability than the bentonites and this, combined with low initial cost, makes them more economical than any other type of clay.

Western Bentonite

This type of clay is characterized by a combination of high green strength and high permeability. Since a smaller quantity may be used than fire clay, a safe permeability will still result even if a finer grain sand is used. It requires intensive mixing for good results. It is workable at a lower moisture content than fire clay.

Having higher dry strength than any other type of clay, it would logically be chosen, either used straight or in combination with other clays, for making heavy nonferrous castings or for those with such gating as to create cutting and erosion problems.

This same dry strength results in the sand baking rather hard in flasks, creating a difficult shake-out and lumpy sand which is sometimes difficult to retemper and recondition. Western bentonite should not be used where the design of casting or type of metal is such as to create danger of cracked castings.

Southern Bentonite

Southern bentonite is higher in green strength and permeability than western bentonite. It combines these values with moderate dry strength. It gives easier shake-out and fewer lumps in sand than any other type of bond clay.

Southern bentonite makes a sand of high flowability, that is, one which rams easily to a hard surface, thus producing excellent finish. Southern bentonite is also unusual in that it mixes readily with sand, even without an intensive mixer, and is, therefore, the only bond clay which may be used with safety by foundries which do not have mechanical mixing equipment.

Thus it is seen that the clay should be carefully selected to fit the individual foundry condition. Failure to so select the clay based on the job to be done, and the effort to make any one clay fit all conditions, are reasons why synthetic sand has sometimes been abandoned, although it should have had application in the particular foundry.

Relative Clay Values

The relative values of clays are given in Table 1. It should be kept in mind that combinations of clays frequently give better results than any individual clay.

B. Semi-Synthetic Sand Program —Foundrymen say that they are using semi-synthetic sand when they are using part synthetic sand and part naturally bonded sand. It may be that a local natural sand will be particularly well suited to a particular job, and the foundryman will desire to continue using it.

At the same time, he may realize the superiority of synthetic sand for another type of work. And, sometimes, a mixture of natural and synthetic sands may give excellent results. For instance, the addition of a small amount of natural sand to a synthetic sand will reduce the rate of drying out.

It is sometimes the case that good base sands of the proper grain size are not locally available. It may then be cheaper to buy the best available low bonded molding sand and bring it to proper working condition by the addition of bond clay. The clay may be mulled with the sand or added in any other convenient manner.

Fire Clay Additions

Any particular sand might be strengthened and made more refractory by the addition of fire clay; its dry strength might be increased by the addition of western bentonite; or its flowability and workability might be improved by the addition of southern bentonite. It is important to remember that the clay has far more effect on the properties of the finished sand mixture than does the sand grains.

C. Rebonding Program — Some foundries continue to use satisfactory naturally bonded sands and use bond clays only to extend the life of the sand. It is very costly to use sand until its strength has been burned out and then discard it. The grain may be perfectly good and require only the addition of bond clay to again make it workable.

In this method, a small amount of clay (1) may be added to the regular facing sand mixture; (2) added on top of the natural sand at the shake-out; (3) mixed with the new natural sand before it is added; or (4) a small amount of clay might be placed on top each mold before the shake-out.

Some naturally bonded sands, such as Albany, are well liked for their grain distribution, but are frequently unsatisfactory and expensive in use because of their low strength. It is a very simple matter to increase their strength to good workable levels, with no appreciable effect on permeability, by the addition of small amounts of bond clay.

Mold Production

This saves money by extending the life of the sand and, sometimes much more money by increasing production. A molder is able to pound out many more molds per hour from a flowable, strong, open sand than from a weak, friable sand which must be babied along and which may cause frequent mold losses from drops.

Such weak naturally bonded sands, when used without the addition of clay, are usually run very wet in order to get workability, which much increases the danger of scrap from the gas produced. The amount of gas produced from various sands is given in Table 2.

Bond clay is of particular economy in bonding burnt core sand

Table 1

Relative Values of Bond Clays
(Michigan City Sand Mulled with Clay as Shown)

Bond		Tempering Water,	Green Compressive Strength,	Dry Compressive Strength,	Green Permeability	Hot Strength, 2000° F.,
Clay	Per Cent	per cent	psi.	psi.		psi.
Fire Clay	12½	4½	9.27	38.3	100	325
Southern bentonite	4	2½	9.19	31.0	175	25
Western bentonite	5	2½	8.69	53.1	171	490

Table 2

GAS EVOLUTION FROM VARIOUS SANDS

Sand	*Tempering Water for Proper Workability, per cent*	*Gas Evolved at 1800° F./Cu. Ft. Sand, cu. ft.*
Ottawa silica sand, 95 per cent Western bentonite, 5 per cent	2.5	232.3
New Albany sand	4.8	502.4
New Ohio sand	7.8	778.3

into a molding mixture, since the sand otherwise is an item of expense in disposal. Such sand usually has good flowability and permeability, while strength may be regulated to suit any job. The cost of hauling burned sand to a mixer to be rebonded is no greater than the cost of hauling it to a dump.

The cost of hauling the rebonded sand to the point of use is no greater than the cost of hauling in an equal amount of new sand. In fact, the cost may be less, since a synthetic sand can be prepared of twice the strength of natural sand, thus halving the quantity required.

Rebonded Sand Costs

A gloomy picture is sometimes presented to the smaller non-ferrous foundryman, who is told that to rebond sand he must haul the materials to and fro in his foundry, thus creating a prohibitive expense.

As seen from the foregoing, these hauling costs are usually lower with rebonded sand than with natural sand, and the actual cost of the rebonded sand is made up only of materials and mixing costs.

The total cost of a sand bonded to the strength of new naturally bonded sand will usually be less than $1.00 per ton, and this may be compared to the delivered cost of new natural sand. The cost of sand rebonded only to normal workable strength is, of course, much lower.

Advantages of Naturally Bonded Sands—Such sands are usable with a minimum of equipment, or with none at all. They retain moisture better than synthetic sands and are easier to patch and repair. They are usable over a wider moisture range than synthetic sands.

Disadvantages of Naturally Bonded Sands—Being a naturally occurring product, naturally bonded sands are variable in quality. Large quantities of materials must be handled and stored for winter. They frequently contain fluxes and impurities, and are lower in refractory value than synthetic sands.

Silt in Naturally Bonded Sands

Because they contain fine silt they are workable only at much higher moisture contents than is synthetic sand, and are definitely less safe in use. They are costly in use because they are discarded when their strength has been burned out, although the grain may still be perfectly good, and require only the addition of bond clay to again make them workable.

Disadvantages of Synthetic Sands—Since they are workable at a low moisture content, the loss of water by evaporation is more serious, and synthetic sands are said to dry out faster than naturally bonded sands. Because of their high flowability they are likewise more brittle than naturally bonded sands, and are more difficult to patch. They require more mixing equipment than the naturally bonded product.

Advantages of Synthetic Sand—The two outstanding advantages of synthetic sand are ease of control and economy. Since they are made from individual components selected and blended by the foundryman under his own direction, they can be made exactly as required and varied when necessary. By constantly re-using the same sand and by reclaiming burnt core sand, the cost of molding materials is held to a very low figure.

Summary

No attempt has been made to give specific sand mixtures because of the great variety of work made in non-ferrous foundries. Also, no attempt has been made to give physical characteristics of sands for various metals because the subject is so thoroughly and ably covered in the A.F.A. *"Recommended Practices for the Sand Casting of Non-Ferrous Alloys"* (published in 1944).

Synthetic sand is cheaper and permits closer control than naturally bonded sands. One car of bond clay will replace about 20 cars of naturally bonded sand, thus reducing the volume of materials handled. Closer control means definitely lower scrap in synthetic sand foundries.

Since southern bentonite can be used without intensive mixing equipment, it is now possible for any non-ferrous foundryman to get some of the advantages of bond clay in extending the life of his sands, producing sands of better working values and definitely decreasing his costs.

Specifically, the non-ferrous foundryman needs a fine grained sand, and that usually means constant danger from blows when using the high moisture content necessary with naturally bonded sands. In using synthetic sands, he creates far less gas and thus solves one of his major sand problems.

PATTERN REDESIGN

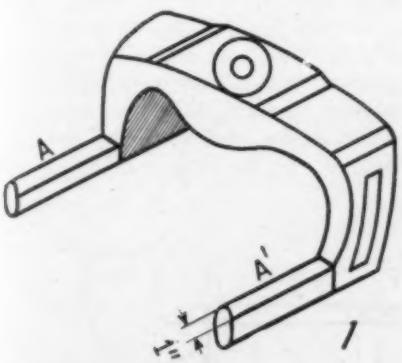
for Increased Production

By Ernest C. Moorhead,
Consulting Foundry Engineer,
Laconia, N. H.

• Use of sample or temporary pattern equipment for production castings often prevents maximum production. Redesign of pattern equipment for efficient operation is sometimes difficult, but time and thought given to adapting the pattern for increased production may mean the difference between profit and loss in the jobbing foundry.

IN many foundries, especially those of the jobbing type, certain castings are made from an original pattern for many months or possibly years. In many such instances, production could be increased from 100 to 500 per cent by some minor changes to the pattern design and equipment without necessarily changing the casting proper.

This lack of maximum production from a given pattern is the fault of no particular individual, as most patterns can be made in several different ways from the same drawing. Besides, designers of machines and parts are not always sure that the original design is exactly what they will require, and changes may be necessary after the sample castings are received from the foundry.



Due to this line of thought, many patterns are made at the least possible expense and are sent to the foundry for samples. Many times the samples are satisfactory and immediately more castings are ordered. As time goes on, the foundry regularly receives orders to be made from the so-called temporary pattern. Orders of this kind generally are filled in a piecemeal fashion, and many times at a loss to the foundry. Thus, a minimum production is continued indefinitely.

To adapt such pattern equipment to cope with this increase in production, the foundryman must study and really ponder over the patterns under consideration. This is not always easy, and sometimes takes weeks of thought to reach a definite conclusion. If the foundryman is successful in his efforts, he finds himself greatly rewarded, and the satisfaction that is his is worth more to him than money.

In any line of work, where there is a job to be done which can be made only by certain persons, because of the skill required, it can be accepted as axiomatic that the job is not being made in the easiest or the best way. Personally, the author does not like to think of a tough job in the foundry that cannot be made into an easy one.

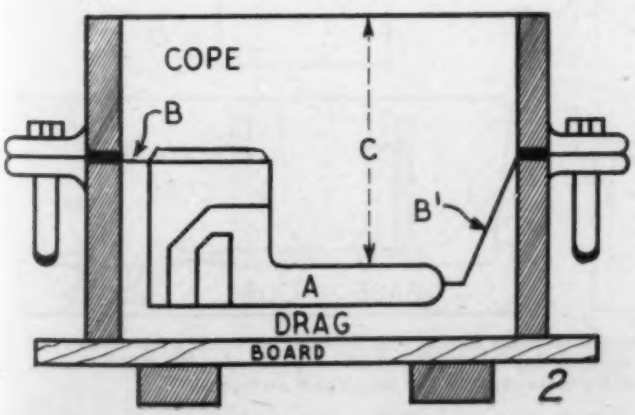
In the following, the author points out how small pattern changes can greatly increase the foundry production and save a lot of supervision and attention on jobs in the "breaking even bracket."

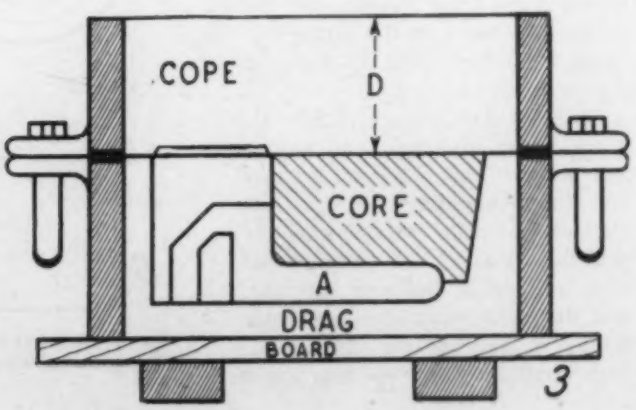
Figure 1 is a sketch of a malleable casting that formerly was made on a side floor in a 20x26-in. wooden flask with a 6-in. cope and a 7-in. drag. The casting, however, is somewhat more complicated than is shown, but the only parts of the pattern that need be considered are the arms (A and A¹, Fig. 1), which make necessary a deep parting line (B-B¹, Fig. 2) at the joint of the flask.

Note the depth of cope in Fig. 2, indicated by line (C). Due to this heavy pocket of sand which extends the full length of the cope, it was necessary to set gaggers through this pocket to insure a good lift and to keep the cope from falling out while the mold was being closed.

As originally made, the drag was rammed on a "clay match" 5 in.

Fig. 1—Sketch of casting on which low production was encountered because of molding method used. Fig. 2—First method of molding. Fig. 3—Use of cores to simplify molding, reduce losses and increase production.





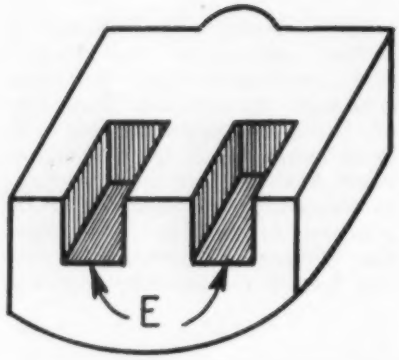


Fig. 4—When molded in green sand, without cores, the pockets lifted against one another causing high mold repair time and low production.

deep, and the drag and the "match" were about as much as a man could handle. With this equipment, a jobbing molder made ten castings per day, with a heavy loss.

The arms A-A¹ are only one in. wide, but the whole cope surface had to be rammed just to get the impression of these arms, or a surface of 2-in. width, far beneath the body of the casting, as shown in Fig. 1.

To simplify the molding operation, reduce the cope lift and eliminate the use of gaggers in the cope, a block core 2 in. wide and 7 in. long and 5 in. high with plenty of taper, to avoid dragging sand when the cores were being set, was made. Two of these cores were used in each mold, one core over each arm. It might be well to add that, in the manner the "clay match" had to be made, the depth of the lift in cope was about doubled. In the original method, the shrink and pressure heads of the gates were also in the pocket between the arms, which complicated matters.

Figure 3 shows the cores in place. Core prints, of course, were added to the pattern, which raised the parting line level with the joint of the flask, as shown. By adding these core prints, the cope became practically a "flat back" and permitted all the green sand between the core prints to remain in the "drag" instead of being lifted in cope, as shown in Fig. 2.

Because this change made the parting line so simple and easy, a new pattern was made on a "cope and drag" molding board, which did away with the old "clay match" or follow board. The patterns then were put on a "rollover machine" and the machine molders now make 60 to 70 castings per day with a very small loss. The castings are of a better grade and more accurate.

In cases like the foregoing, some foundrymen buy metal flasks with joints which follow the irregular parting line of the pattern. At times, this is a very good way to make irregular parting line work, especially if that parting is extremely irregular. However, metal flasks are expensive and a foundry often finds itself with a lot of money tied up in metal flasks that can be used only on one job. Since the new pattern design provided a very plain cope line, it was found more advisable to use a 16x21-in. snap flask with a 6-in. cope and a 7½-in. drag.

In this case, it was found that the snap flask was better than the metal flask. With a metal flask, cut to the contour of the pattern, the cope would have been very unbalanced, which would have been awkward to handle and would slow down production.

In Fig. 4, note the pockets, marked E, in a simple pattern. Aside from these pockets, which are 2½-in. deep, 2½-in. long, and 1⅝-in. wide, there would be nothing to slow down production. However, these pockets have very little draft and, where two or more pockets of green sand must be lifted in the cope, one usually lifts against the other.

The molder, who originally made this job in a 13x16-in. snap flask, was one of the best. However, he had to set "soldiers" or 20-penny, clay-washed nails into these pockets to bring the pockets up in the cope. Many times, parts of the green sand would pinch off and, because a snap flask was used, it was necessary to place a board behind the cope to lay it flat on the bench so that the broken parts could be mended. Even so, a patched mold resulted.

As originally molded, a good man would make 30 to 38 castings per day of the type shown in Fig. 4, depending on his luck in lifting the cope. Whenever "soldiers," clay-washed nails, etc., have to be used by a molder in making a job, it involves valuable time and the work done is not absolutely safe or foolproof.

To increase production and eliminate mold repair time, an impression was made of the pockets (E) in plaster of paris, and a core box was built around this plaster impression. Core prints were added to the pattern and the job turned over to an apprentice boy. Working piece rate on a squeeze machine, he produces 100 to 125 castings per day. With this small change, any boy in the shop can make the work, as all of the tricky parts of the operation have been removed.

It does not pay to use a pattern which leaves its own green sand cores if these cavities cause the least possible signs of sticking or washing ahead of the iron when the mold is poured. In the long run, cores are

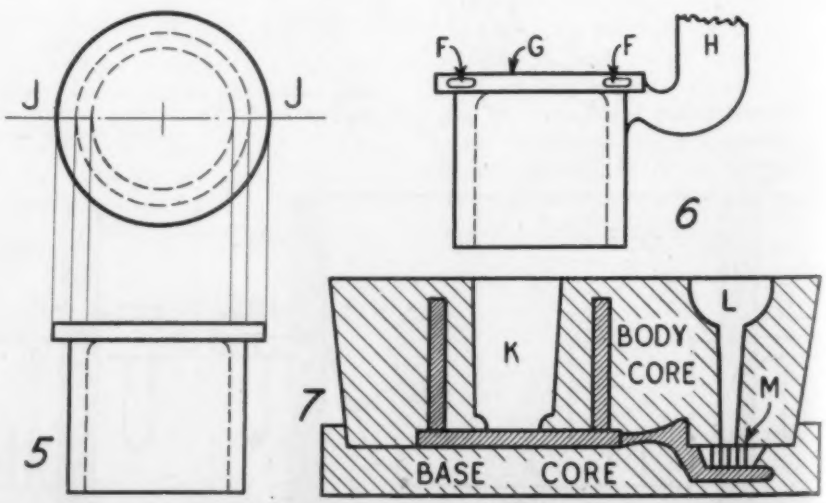


Fig. 5—Sketch of 5 in. dud shell butt casting. Fig. 6—Points at which defects developed in original molding method. Fig. 7—Final method adopted, using two cores instead of the green sand used in the original method.

cheaper than having a molder playing with some ticklish job simply to avoid making a core.

Figure 5 shows a sketch of a 5-in. dud shell butt to be used for practice purposes. When the foundry quoted on this job, it was understood that almost any kind of a casting would do. However, the drawing showed that the casting was to be machined all over.

Naturally, the foundry started to make these castings in the usual manner, using only a plain cope, as shown in Fig. 6. The samples were broken up and it was found that an internal shrinkage took place at points marked (F), Fig. 6.

Shrinkage Overcome

To overcome this shrink, a large feeder was set up as shown at (H), Fig. 6, which served its purpose, but grinding off this feeder cost more than to make the casting. However, at this stage the work was put into production.

The machine shop, which was in another city, did not start to machine the castings for some weeks, and the foundry had several thousand made. When the machining started finally, it was found that all of the castings were scrap, inasmuch as it was also found that the castings had small dirt and pin holes on the top surface shown at (G), Fig. 6. Thus, the foundry lost 100 per cent of several weeks' work on what had seemed to be the simplest kind of a job.

Since the castings now required had to be absolutely perfect and were required to take a high polished finish, it was assumed that the castings could not be cast by the plain molding system, as originally planned, with any degree of safety on the part of the foundry.

Castings Made in Core

Therefore, it was reasoned that the only way to make these castings in sufficient quantity was to turn to the pattern upside down. To make the castings in this position was of course impractical, so one pattern was screwed in the center of a core box, as shown in Fig. 7, and the whole casting was made in a core.

This core consisted of a base core and a body core, as shown in Fig. 7. A heavy shrink head was placed in the inside center of the pattern, which resulted in a big saving to the foundry as no grinding was necessary. The head, after being broken off, left only about ¼-in. still intact on the casting, and this was machined off in the machine shop when the inside of the shell butt was machined.

Core Location

The body core and the base core were made to locate the two core parts so that the pouring gate and the skim core would member properly when the two cores were put together. Provision was made in the base core to insert a skim core (M) and a lead gate, the skim core being set in the base core, as shown in Fig. 7, which was connected with the pouring gate (L). The base core was placed on the molding floor and the body core placed on top of it and weighted down for pouring.

The core boy received around 7 cents per pair of these cores, and with the sand and oil added, this method was less expensive than making the castings in green sand, if it had been possible to make them in the same position as made in the core or as made originally. Two hundred of these shell butt castings were cast daily for many weeks, which equalled the production reached when the job was started in green sand. All of the molders in the shop took turns pouring these shells at the end of the heat and were paid for the pouring.

Pattern Changes

Malleable foundries often receive patterns that are away out of proportion. The castings crack and shrink, and serious trouble often develops if the foundryman tries to ignore the characteristics of high combined carbon iron.

Under such conditions, the first impulse would be to phone or write the customer about changing the pattern somewhat. A better plan is to make a mold in the usual manner and pour it with plaster of paris. Have the patternmaker dress this plaster cast up neatly along the lines desired and make a few castings from this plaster cast. This will give the customer a working part to try out, and the working patterns need not be disturbed until it is absolutely certain that the foundry trouble has been eliminated and the customer is satisfied with the castings from the new design.

Grain Refinement of MAGNESIUM CASTING ALLOYS

By James A. Davis, Research Engineer, L. W. Eastwood, Assistant Supervisor, and James DeHaven, Research Engineer, Battelle Memorial Institute, Columbus, Ohio.

METALLURGISTS, in recent years, have become increasingly aware of the importance of grain size as a factor determining the useful characteristics of metal products. Grain size control can be applied whenever new grains are formed or old ones grow during manufacture.

Usually such grains may form or grow either (1) from a solid such as by an allotropic transformation or by recrystallization and grain growth when annealing worked materials, or (2) from a liquid melt during the process of solidification.

The application of grain size control of new grain formation or growth in a solid has been utilized for a longer time and with greater general success than the application of grain size control methods to the formation of new grains during solidification.

Indeed, many alloys of various base materials are cast today in many foundries without any attempt at grain size control. The light alloy foundries are outstanding in their efforts to control the cast grain size, and thereby control one of the factors which affects the quality and usefulness of their product.

The importance of grain size control in a magnesium foundry is well illustrated by the work of Achenbach, Nipper, and Piwowarski[1] on the relationship of grain size and foundry characteristics. A recent paper by Busk and Phillips[2] reports a systematic investigation on the relationship of grain size of ASTM-4 and ASTM-17 alloys to the various mechanical properties.

Hot Shortness

The foundry characteristic most affected by grain size is hot shortness. While the magnesium alloys are not particularly hot short, they are quite frequently subjected to considerable strain after casting and while the metal is cooling in the mold.

Magnesium melts have low specific heat by weight and are poured at relatively low temperatures. Because of these two factors and the usual thin sections, internal cores do not collapse readily, with the result that considerable strain is produced in the hot castings.

It is quite well known that epidemics of hot cracks in a magnesium foundry are quite frequently associated with poor grain refinement.

The effect of grain size on the mechanical properties is quite marked. According to Busk and Phillips,[2] an increase in grain size from 0.004 in. to 0.015 in. has the effects upon various mechanical properties of sand cast test bars shown in Table 1.

In addition to the adverse effects of increased grain size previously cited, there is some evidence that an increase in grain size interferes with the solution heat treatment, making a longer time at the solution temperature necessary.

The cause of this interference is probably twofold: (1) the particle size of the beta constituent tends to increase with an increasing grain size; (2) the larger grain produces a greater distance for diffusion because the beta particles are generally concentrated at the grain boundary, and this soluble constituent at the periphery must diffuse into the grain. There is also some evidence that an increase in grain size increases the quantity and augments the deleterious effect of grain boundary unsoundness such as microporosity.

There are factors, such as the degree of microporosity and perhaps the quality of the heat treatment, which are more important and have a greater bearing upon the quality

• ***As part of the general program sponsored by the Office of Production Research and Development of the War Production Board, and under the guidance of the Office of Scientific Research and Development, this paper describes a method of obtaining grain refinement in magnesium alloy melts which have been degassed and cleaned by methods developed under another part of the program. In general, grain refinement of magnesium alloys containing aluminum may be obtained by treatment with carbonaceous materials.***

of the casting than its grain size. However, the available information definitely indicates that grain size control in magnesium castings is an essential feature of high quality.

It should be noted that it is quite possible to obtain too much grain refinement because such fine-grained castings, especially with high aluminum content, will germinate and produce very large grains up to ½ inch in diameter, or even greater, during the heat treatment. When such germination occurs, the mechanical properties are very low.

Such excessively fine grains are usually obtained by the combination of otherwise acceptable grain refinement with too rapid solidification, as in those parts of castings adjacent to chills or in thin fins.

Table 1[5]

Effect of Grain Size Increase (0.004 to 0.015 In.) on Mechanical Properties of Magnesium Sand Cast Test Bars

Property	Reduction in Properties, per cent — Heat Treated ASTM-4*	Heat Treated and Aged ASTM-4*	Heat Treated and Aged ASTM-17*
Tensile strength, psi.	12	12	12
Elongation, per cent in 2 in.	35	20	**
Tensile impact resistance, ft.-lb.	30	35	55
Endurance limit***	25	25	25

*ASTM-4 contains about 6 per cent aluminum, 3 per cent zinc, and 0.2 per cent manganese. ASTM-17 contains about 9 per cent aluminum, 2 per cent zinc, and 0.2 per cent manganese.
**Elongation values for heat-treated and aged ASTM-17 are low, and the reduction, if any, produced by the increase in grain size is inconclusive.
***Data for ASTM-4 alloy, heat treated, are somewhat scattered. The data on ASTM-17 alloy, heat treated and aged, are somewhat limited.

Commercial Methods

The present commercial method of obtaining grain refinement in magnesium alloy melts consists of the well-known process of superheating. Normally, the metal is melted in a large bulk melter, and then transferred to refining pots holding from 60 to 500 lb. of metal.

These small batches of metal are treated with a refining flux at around 1325-1350° F. The melts then are superheated to 1600-1700° F., after which they are cooled to the pouring temperature and poured as soon thereafter as possible.

This method is generally reliable, but there are instances in which the grain of certain heats refines with greater difficulty than in other heats, the exact cause of these variations being unknown.

It is a characteristic of this method of obtaining grain refinement that prolonged heating at 1700° F. may produce a rather coarse grain.[7] Holding the melt at fairly low temperatures for a short period of time also will produce a coarse grain.

Some variation in grain size from melt to melt is a characteristic of all casting alloys, magnesium base or otherwise, and most of the variables which cause these differences are unknown. However, some of these factors which control the grain size of castings poured from properly superheated magnesium alloy melts are known.

Among these are the effects of certain minor elements and the amount of scrap in the form of gates and risers in the charge. Beryllium, calcium, and cerium increase the grain size markedly.

It is sometimes claimed that a fine-grained ingot will produce finer grained castings than a coarse-grained ingot. Consequently, it would be expected that the larger proportion of scrap from castings poured from superheated metal in the charge, the finer the grain of the castings poured from the melt.

Superheating Magnesium Alloys

In general, however, most of the superheating effect is lost upon remelting and very little carry-over of grain refinement from the preceding melting operation can be detected.

It should be noted that the results of the work on W.P.B. Project NRC-550[8] on carbothermic magnesium showed that it differs from electrolytic metal in respect to the factors determining its grain size in castings. This project was carried on concurrently with W.P.B. Project NRC-546, a portion of the results of which are reported in this paper.

On the basis of the results obtained in this work, the differences noted between carbothermic and electrolytic magnesium are probably caused by the larger amounts of carbon in the carbothermic metal.

It must be concluded that the present commercial method of obtaining grain refinement in magnesium alloys by superheating is very widely used and is generally successful. However, the method has certain disadvantages:

1. The process is carried out on relatively small batches of metal. This is partly necessitated by the fairly rapid cooling required from the superheating temperature, and in part by the present commercial methods of cleaning the melt. In any event, the handling of small batches of metal requires a considerable number of small furnaces for the refining and superheating operation.

2. The relatively high temperature of the superheating operation requires considerable time and fuel, and the exposure of the steel pot to the high temperatures causes deterioration of the pot and shortens its life, thereby increasing the cost of the melting operation.

3. The exposure of the melt to the steel pot at high temperatures also accentuates iron absorption, which decreases the resistance of the alloy to corrosion.

4. Because of the time, fuel, and labor required, as well as the considerable amount of equipment and short pot life, the cost of the process is substantial.

5. The working conditions in that portion of the melting room devoted to the refining and superheating operation are not generally good, particularly during warm weather.

6. The temperature-time cycle must be carefully controlled if uniform results are to be obtained. Any delay, necessitating holding the metal near the pouring temperature after the superheating operation, tends to coarsen the grain and nullify the superheating effects.

New Method of Grain Refinement

Although the superheating operation for grain refinement has been used for many years in foundry operation, it is quite evident that some improvement in the process would be desirable.

In the early part of the work on W.P.B. Project NRC-546,[4] it was

reported that certain carbonaceous gases produced grain refinement if they were bubbled through the melt for a few minutes at a melt temperature near 1400° F. The initial results definitely indicated that the grain refinement obtained by this method was at least equivalent to that obtained by the normally used superheating operation.

Since this method could be applied to large melts at substantially lower temperatures than those used in superheating, the process did appear to have considerable practical possibilities. Consequently, experimental and development work was started to obtain the necessary information to apply the procedure on a sound and practical basis.

A new method of degassing and cleaning the melt to replace the normally used refining flux also has been developed, as described in a separate paper.[5]

This cleaning and degassing operation was applicable to large melts, also. It was logical, therefore, that a simple grain-refining operation applicable to large melts previously treated with a refining flux or with chlorine was also desirable.

Experimental Work

For this reason, most of the experimental work on grain refining was done on melts which had previously been cleaned and degassed with chlorine. In general, the grain-refining operation might precede, be simultaneous with, or follow the cleaning and degassing operation.

The experimental methods were quite similar to those described in the paper on the reduction of microporosity.[5] The usual synthetic green sand, consisting of silica sand with 4 per cent of bentonite, 1 per cent of boric acid, 3 per cent of sulphur, and 1 per cent of glycol, tempered with about 2 per cent of water, was used for green sand molds.

The melts were prepared either by the standard commercial method of using a refining flux such as No. 310, or more usually they were cleaned and degassed with chlorine as described in a separate paper.[5] The mechanical properties of test bars were obtained by using the four-bar castings shown by Fig. 1.

The melt quality, in respect to gas content, was obtained as described in reference 5 by using the wedge casting shown by Figs. 2, 3, and 4.

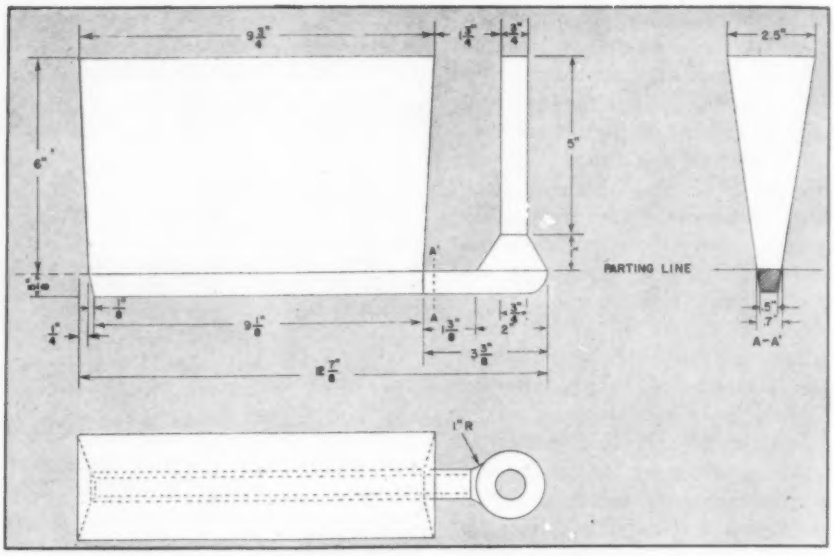


Fig. 2—Views of the wedge casting used in the investigation.

The use of these two castings, the four-bar and the wedge, also makes it possible to obtain data on the grain size obtained in a relatively light and in a relatively heavy section.

All grain size measurements were made on test bars and at a point about one in. above the bottom of the wedge by comparison with the Dow grain-size chart. All grain size measurements are expressed in thousandths of an inch, because this method has greater physical significance and is more readily visualized than grain size numbers or the number of grains per unit of area.

Cooling Rate

The grain size depends to some extent upon the cooling rate; therefore, test bars in general have a grain size of 0.001 to 0.002 in. finer than samples cut from the bottom of the wedge castings where solidification is slower.

It will be shown later that the pouring temperature has relatively no effect upon the grain size of the sand castings, except at very low pouring temperatures. Consequently, this factor, though more or less of a variable in the foundry operation, is not very important in its effect upon the resulting grain size of the sand castings.

Experience has indicated that a light, fine-grained sand casting, such as the four-bar casting, will have a grain size of approximately

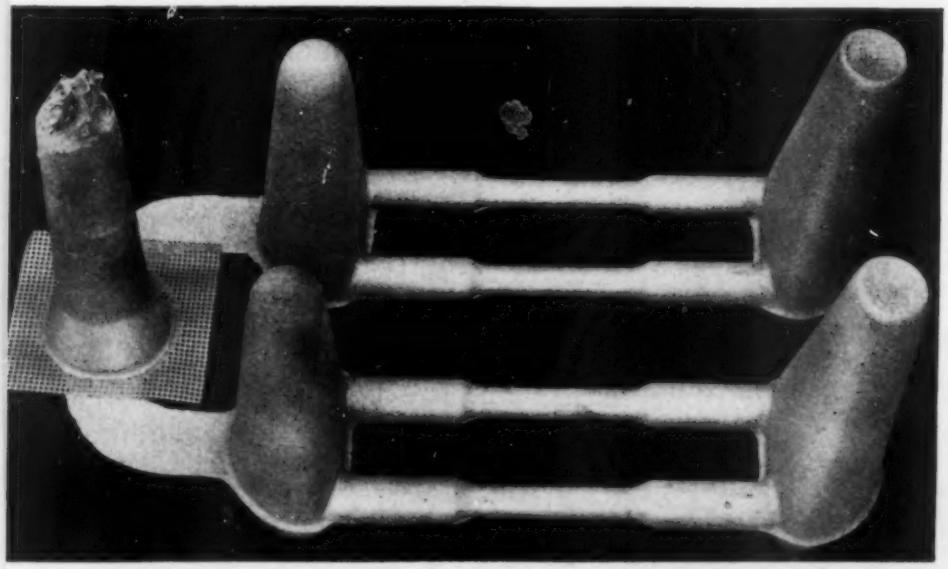
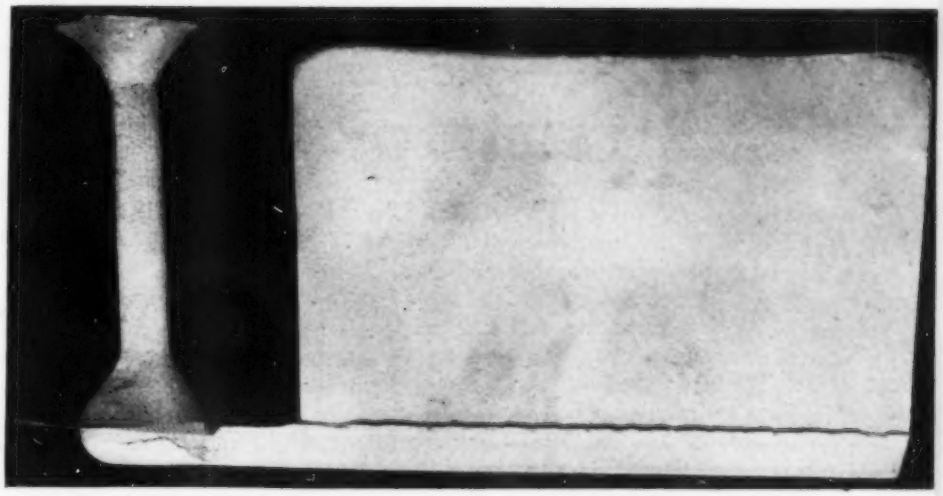


Fig. 1—Four-bar pattern test-bar casting.

Fig. 3—Photograph of the wedge casting.



0.004 in., whereas the wedge casting poured from the same melt generally will have a grain size of 0.005 to 0.006 in. because of the heavier section and slower rate of solidification.

Very fine-grained castings will have a smaller grain size than this, whereas coarser-grained castings may be considerably coarser than the figures given. Qualitatively, the grain size may be classified into five groups as being very fine, fine, moderately fine, slightly coarse, and coarse. Table 2 shows the grain sizes of the four-bar and wedge castings corresponding to these five groups.

In general, when grain sizes of 0.002 or 0.003 in. are formed by the attainments of good grain refinement plus rapid cooling, such as obtained next to a chill or in a thin fin, these fine grains may grow during heat treatment to form excessively coarse grains or "germinated grains." Consequently, these very coarse grains produce a very defective casting.

Table 2

GRAIN SIZE GROUPS

Grain Size, Qualitative	*Grain Size, in.* — *Wedge*	*Test bar*
Very fine	0.004 or less	0.003 or less
Fine	0.005	0.004
Moderately fine	0.006-0.007	0.005-0.006
Slightly coarse	0.008	0.007
Coarse	0.009 and above	0.008 and above

This defect is particularly apt to occur in alloys having a high aluminum content. Accordingly, excessively fine grains should be avoided and thin fins should be removed from the casting before the solution heat-treatment operation.[8]

Effect of Grain Size upon Microporosity Occurrence—It was noted previously that grain size control was necessary, and one of the reasons cited was that microporosity tends to be more pronounced with coarse grain.

Several heats were made in which the melt was carefully cleaned with No. 310 flux that had been thoroughly melted and dried before it was stirred into the melt. Some of these heats were superheated to produce grain refinement, while others were not. The results of this work are summarized in Table 3.

These data on the height of sound metal definitely indicate that the coarse grain accentuates the occurrence of microporosity in the wedge casting. The reason for this is not altogether clear, but it is probably logical that the difficulties of feeding the space around each individual grain in the partially solidified melt increases with an increase in grain size.

Grain Refinement by Use of Various Carbon-Containing Gases — It was found in early experiments that gases, such as carbon dioxide, acetylene, and natural gas, all produced grain refinement equivalent to that obtained by the normal superheating operation.

To avoid gassing the melt, it is, of course, necessary to use dry gases for the attainment of grain refinement. The dry natural gas was very effective and readily available. Therefore, most of the work on this type of grain refinement was performed with this gas.

The hydrogen in the natural gas apparently did not break down into atomic hydrogen, but rather into molecular hydrogen, a form which is not readily absorbed by the melt.[5]

Typical results obtained on ten different heats in which the grain was refined by bubbling dry natural gas into the melt are listed in Table 4.

These data clearly show that good grain refinement has been obtained by bubbling natural gas through the melt for 5 min. at a melt temperature of about 1400° F.

Attempts were also made to obtain simultaneous degassing and grain refinement by using chlorine and dry natural gas at the same time. These results were generally unsatisfactory; apparently the small amount of carbon which is formed in the melt is rapidly swept out by the chlorine before it has an opportunity to dissolve preparatory to its function as a grain-refining constituent.

It was of considerable interest to know whether or not the dry natural gas effectively refined commercially pure magnesium and the effect, if any, of the three common alloying constituents present in commercial alloys.

These three common alloying constituents are aluminum, zinc, and manganese. Consequently, one melt each of commercially pure magne-

Table 3

EFFECT OF GRAIN SIZE ON OCCURRENCE OF MICROPOROSITY

Number of Heats	*Metal Treatment*	*Height of Sound Metal in Wedge, in.* — *Min.*	*Max.*	*Avg.*	*Average Grain Size in Wedge, in.* — *Min.*	*Max.*	*Avg.*
7	Cleaned with No. 310 flux, using good practice, not superheated.	2⅛	3	2¼	0.010	0.040	0.020
6	Cleaned with No. 310 flux, using good practice, melt superheated.	3½	3¾	3⅝	0.004	0.007	0.005

sium, magnesium with 1.5 per cent of manganese, magnesium with 3 per cent of zinc, and magnesium with 6 per cent of aluminum was melted and the melt treated with natural gas at a temperature near 1400° F. (Table 5).

The results listed in Table 5 clearly show that aluminum is necessary in the melt before grain refinement can be obtained by the use of a carbon-containing material as a grain-refining agent. This limitation is also apparently true for the superheating operation. The theoretical significance of these data will be discussed later.

Natural Gas Treatment

The optimum melt temperature for the natural gas treatment is, of course, of considerable practical interest. Several heats were prepared and the melt treated as indicated by the date in Table 6.

The melts were treated with natural gas, using progressively increasing melt temperatures at the time of the grain-refining treatment. The results on the mechanical properties and grain size of the wedge and test bar are shown also by Table 6.

These results definitely indicate that a melt temperature at the time of the natural gas treatment should not be less than 1350° F. The theoretical significance of this observation will be discussed further at a later point in the paper.

The effect of time of natural gas treatment at a melt temperature of 1400° F. was investigated. The melt was first cleaned and degassed with chlorine, after which the grain size of the wedge and test bar were both about 0.010 to 0.015 in.

After treating the melt for 3 min. with dry natural gas, the grain size of the test bar was 0.006 in., and after a treatment of 6 min. the grain size was 0.004 in. No further improvement occurred, although the melt was treated with dry natural gas for 2 hr., during which time several test castings were poured.

The reduction in grain size effected during the first 6 min. of the dry natural gas treatment was also reflected in slightly higher tensile properties.

The effect of remelting and the effect of holding at 1350° F. was investigated, using melts of ASTM-4, ASTM-17, A-8, and AZ-91 alloy compositions which had been treated with the dry natural gas.

It was found that remelting and re-treating with dry natural gas did not produce a finer grain by successive treatments than that obtained by the first treatment.

It was also found that the grain size of ASTM-4 alloy was coarsened somewhat by holding the melt at 1300° F. However, ASTM-17, A-8, and AZ-91 compositions were not markedly coarsened by this holding treatment. It is quite likely that a lower holding temperature would have coarsened all of the alloys. In this instance the effect of holding the ASTM-4 composition after the natural gas treatment is quite similar to the effects produced by holding at the same temperature after superheating.

Carbonaceous Gas Treatment

It may be concluded that a treatment with a carbon-containing gas, such as dry natural gas, refines the grain as effectively as the standard superheating treatment. Furthermore, about a 6-min. treatment is ample for a heat of approximately 120 lb.

Like grain refinement by superheating, the grain refinement obtained with dry natural gas is lost by remelting and by holding the melt at a low temperature. However, additional experience does indicate that metal which has been treated with a carbon-containing material does sometimes show an unusually fine grain when the metal is remelted.

Such a carry-over of grain refinement is not reliable. Later experience also indicates that melts which have been treated with a carbon-containing material do not coarsen quite so rapidly as superheated metal, and then only at very low temperatures near 1250° F.

As compared with grain refinement by superheating, the new method of treating with a carbonaceous gas has the following advantages:

1. It probably can be applied to large melts.

2. When used in conjunction with cleaning and degassing with chlorine[5] the refining furnace can be eliminated, with consequent saving

Table 4

GRAIN REFINEMENT BY USE OF CARBON-CONTAINING GAS

Number of Heats		Grain Size, in. — Wedge Min.	Wedge Max.	Wedge Avg.	Test Bar Min.	Test Bar Max.	Test Bar Avg.
10	Treated with natural gas after a chlorine flux, melt treated at about 1400° F.	0.004	0.020	0.008*	0.003	0.007	0.005

*One of the wedges poured in the 10 heats had a grain size of 0.020, while the test bar poured from the same melt had a grain size of 0.004. Eliminating this erratic grain size, the wedges have a range of grain size of 0.009 to 0.004 and an average of 0.0065.

Fig. 4—Radiograph of the wedge casting showing the distribution of microporosity represented by the dark, cloudy areas on the photograph.

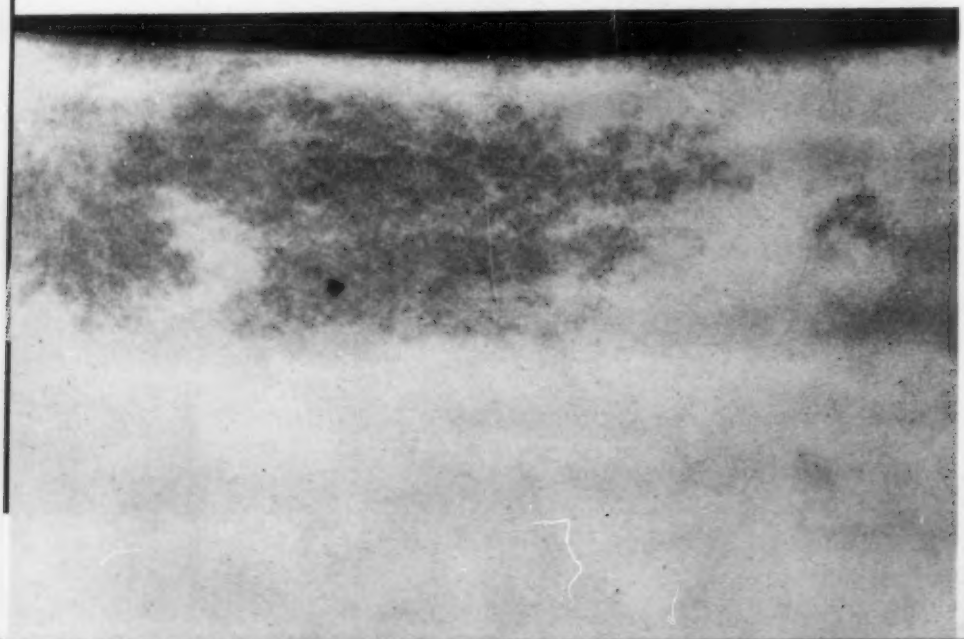


Table 5

Relationship of Alloy Composition and Grain Refinement Obtained by Natural Gas

Specimen No.	Alloy	Condition and Treatment	Castings Poured	Pouring Temp., °F.	Height of Sound Metal in Wedge, in.	Grain Size, in.	Heat Treatment	Mechanical Properties* Tensile Strength, psi. Min.	Tensile Strength, psi. Avg.	Yield Strength, psi. Min.	Yield Strength, psi. Avg.	Elongation in 2 In., per cent Min.	Elongation in 2 In., per cent Avg.	Reduction of Area, per cent Avg.
239A	Comm. pure	Cl_2 flux, 15 min. at 1250-1310° F.	Wedge Test Bar	1400	Columnar		A.C.	10,700	10,750	6,700	7,550	2.5	2.5	1.4
B	Mg	Natural gas, 5 min. at 1400° F.	Wedge Test Bar	1400	Columnar		A.C.	10,300	10,800	2,000	2,450	5.7	5.8	4.8
220A	Dow M	Cl_2 flux, 15 min. at 1350-1400° F.	Wedge	1400	5	0.060								
B	(1.5 per	Natural gas, 5 min. at	Wedge	1400	4¾	0.100								
B	ct. Mn)	1350° F.	Test Bar											
241A	Mg	Cl_2 flux, 15 min. at	Wedge	1400	4	0.035								
A	+	1260-1310° F.	Test Bar			0.025	H.T.	23,600	23,750	6,200	6,250	9.1	9.1	10.5
	3 per						H.T.A.	26,600	26,650	9,100	9,150	9.0	9.0	8.5
B	cent Zn	Natural gas, 5 min. at	Wedge	1400	4	0.035								
B		1400° F.	Test Bar			0.020	H.T.	24,600	24,950	6,200	6,250	9.6	11.0	12.3
							H.T.A.	25,700	26,350	10,000	10,100	7.8	8.1	10.7
240A	Mg	Cl_2 flux, 15 min. at	Wedge	1395	3	0.012								
A	+	1260-1310° F.	Test Bar			0.007	H.T.	34,400	34,500	10,700	10,750	13.6	14.2	15.6
	6 per						H.T.A.	33,800	34,150	11,500	11,750	12.1	12.1	13.8
B	cent Al	Natural gas, 5 min. at	Wedge	1400	4	0.007								
B		1400° F.	Test Bar			0.004	H.T.	36,100	36,350	11,200	11,750	15.7	15.9	18.5
							H.T.A.	32,500	33,900	12,800	12,850	9.6	11.0	11.5

*Mechanical properties based on the results from two test bars.

in time, equipment, and pot life. While these advantages over the regular superheating method are considerable, further work was done in order to obtain an easier and simpler method of attaining grain refinement.

Grain Refinement by Use of Solid Carbonaceous Materials—Since carbon appeared to be the material which produced the grain refinement, some investigation was made of solid carbon-containing additions to the melts.

Solid Grain Refiners

The various materials tried consisted of granulated graphite, granulated aluminum carbide, granulated silicon carbide, and granulated high-manganese high-carbon ferromanganese. It has been noted that before grain refinement could be obtained by the use of a carbonaceous gas, aluminum was necessary in the melt.

Since the necessary ingredients were carbon and aluminum, it seemed logical that the carbide Al_4C_3 might be an effective grain refiner. Several attempts were made to refine the grain with these various solid grain refiners.

All of these materials produced grain refinement, although there were instances in which the results obtained were rather erratic. These failures were attributed to the difficulty of placing these solid materials into the melt without allowing them to become entrapped in flux and dross, which would prevent their partial absorption by the melt.

Most of these experiments were performed by first cleaning the melt with chlorine, and then adding the solid carbonaceous material. There is, of course, the possibility of using such materials during the melting down period, after which the melt could be cleaned and degassed with chlorine.

It was concluded, however, that while such materials do produce grain refinement, the results are not sufficiently reliable to be practical.

One rather interesting observation made during the course of this investigation was the remarkable grain refinement obtained by melting in a silicon-carbide crucible.

Such crucibles contain a considerable amount of silicon carbide, SiC. Approximately 20 melts were made in silicon-carbide crucibles, and in each instance the grain size was very fine.

This grain refinement was attributed to the absorption of some carbide by the contact of the melt with the pot surface. Some silicon pickup was also observed, this amounting to about 0.005 per cent.

Such pots have the advantage of thus providing automatic grain refinement, and they also eliminate iron absorption during the melting operation. This avoidance of iron absorption should considerably improve the resistance of the alloys to corrosion.

The silicon pickup is somewhat objectionable and, with the repeated remelting that is necessary in the ordinary sand foundry, the amount of the silicon pickup would become more substantial.

A further disadvantage of the silicon-carbide crucible for large melting units is the possibility that the refractory will be penetrated by the flux which is required during the melting down operation. These fluxes are very hygroscopic, causing considerable deterioration of the refractory when the crucible is not in use.

It is concluded, however, that the silicon-carbide crucibles, possibly with a carbon lining[6] for large bulk melters, might have some practical possibilities if they were substituted for the present steel pots.

Organic Chlorides Used

Grain Refinement by Use of Volatile Organic Chlorides—Since the active grain-refining agent is carbon, it appeared logical that this element might most advantageously be added to the melt by the use of an organic chloride.

Such chlorides combine with the magnesium melt to form magnesium chloride and free carbon. This free carbon is in the finely divided state ideal for absorption by the melt.

The chlorides investigated were carbon hexachloride (C_2Cl_6) and carbon tetrachloride (CCl_4). The first chloride is a solid at ordinary temperature and pressure, but it volatilizes quite readily. Conse-

quently, it was added by means of an inverted cup which was inserted into the melt.

The heat caused the chloride to vaporize and the vapor bubbled through the melt, which was maintained at a temperature near 1400° F. These materials produced excellent and reliable grain refinement in all instances.

In addition to grain refinement, they also produced at least some degassing and cleaning simultaneously. However, the contact of the melt with the solid chloride is too short for complete degassing and cleaning.

The liquid carbon tetrachloride, however, was vaporized and the melt was subjected to this vapor for 10 to 15 min. in a manner similar to the ordinary chlorine flux. This treatment not only produced grain refinement, but also cleaning and degassing equivalent to that obtained with chlorine.[5]

Chlorine-Carbon Tetrachloride

While the carbon tetrachloride effectively degassed, cleaned, and produced grain refinement simultaneously, considerable difficulty was encountered when introducing it into the melt. A substantial volume of carbon was formed by the reaction with the magnesium melt.

This carbon tended to clog the fluxing tube, thereby causing some mechanical difficulty. This indicated that too much carbon tetrachloride was being used; therefore, the possibility of using a mixture of chlorine and carbon tetrachloride was investigated.

Cleaning, Degassing, and Grain Refining in One Operation—Considerable investigation has been made using a mixture of chlorine and carbon tetrachloride for simultaneously cleaning, degassing, and grain refining. When this mixture is used, the procedure is substantially the same as when fluxing with chlorine alone.

The only difference is that the chlorine is bubbled through a bath of carbon tetrachloride. The latter is volatile and a portion of it is vaporized and carried over with the chlorine into the magnesium melt.

Vapor Temperature

The higher the temperature of the carbon tetrachloride bath, the greater the amount of the vapor carried over. Since both the chlorine and the carbon tetrachloride change from a liquid phase to a vapor phase, both are cooled during use. Consequently, it is necessary to keep the bath of the carbon tetrachloride at least up to room temperature.

The small carbon tetrachloride baths used experimentally would drop during use to a temperature of about 55° F. unless some heat is applied by means of a water bath. At this temperature the vapor pressure is low and not much of the chloride is carried over with the chlorine.

A considerable amount of data has been obtained on this method of metal treatment, and only a portion of this is presented in this paper. Table 7 shows some typical results obtained with the mixture produced by bubbling chlorine through a carbon tetrachloride bath maintained at various temperature levels.

Table 7 shows the effect of the fluxing treatment upon the gas content of the melt as revealed by the height of sound metal in the wedge, the grain size obtained in the wedge and test bar before and after the metal treatment and after holding for a period of 15 min. after the metal treatment. The effects on the mechanical properties are also shown.

Table 8 shows the grain refinement obtained by the use of the mixture, the effect of holding at various temperatures, and the effect of reheating after the melt has been held at a low temperature. These data are the average results obtained on one heat of A-8, AZ-91, ASTM-4, and ASTM-17 alloys.

Grain Sizes

Minimum, maximum, and average grain sizes in the wedge and test bar are shown. The maximum grain sizes listed are the largest grains reported on any portion of a test bar rather than the coarsest average grain size of the test bar. These melts were prepared from 75 per cent scrap and 25 per cent new ingots.

It will be noted that the grain size after melting and before the treatment with the chlorine and car-

Table 6

EFFECT OF MELT TEMPERATURE ON THE GRAIN REFINEMENT OBTAINED BY NATURAL GAS*

Specimen No.	Alloy	Condition and Treatment	Castings Poured	Pouring Temp., °F.	Height of Sound Metal in Wedge, in.	Grain Size, in.	Heat Treatment	Mechanical Properties** Tensile Strength, psi. Min.	Tensile Strength, psi. Avg.	Yield Strength, psi. Min.	Yield Strength, psi. Avg.	Elongation in 2 In., per cent Min.	Elongation in 2 In., per cent Avg.	Reduction of Area, per cent Avg.
208A†	ASTM	Cleaned with No. 310	Wedge	1350	1	0.015								
A	4	flux first, then natural	Test Bar	1340		0.015	H.T.	36,100	36,100	11,600	11,700	9.5	10.0	8.2
B		gas 5 min. at 1220° F.	Test Bar				H.T.A.	34,000	34,450	16,400	16,500	3.9	4.4	4.6
209A†	ASTM	Same as 208A, except	Wedge	1370	½	0.007								
A	4	natural gas added to	Test Bar				A.C.	30,900	31,150	13,600	13,750	6.7	7.0	8.3
B		melt at 1300° F.	Test Bar			0.006	H.T.	39,200	39,850	12,600	12,600	11.0	12.8	14.1
							H.T.A.	39,300	39,800	16,500	17,050	5.8	6.0	6.7
168A	ASTM	Same as 208A, except	Wedge	1390	1¾	0.004								
A	4	natural gas added to	Test Bar			0.003	A.C.	31,800	32,450	14,500	14,950	7.0	7.8	7.1
B		melt at 1360° F.	Wedge		1¼	0.004								
B			Test Bar				H.T.	43,000	43,300	14,400	14,450	17.3	17.3	20.0
							H.T.A.	41,800	42,950	19,600	19,900	5.9	6.8	7.0
210A†	ASTM	Same as 208A, except	Wedge	1390	1	0.004								
A	4	natural gas added to	Test Bar			0.003	A.C.	31,100	31,700	14,800	14,950	6.0	6.3	6.5
B		melt at 1400° F.	Test Bar				H.T.	41,800	42,400	13,500	14,000	13.8	15.1	15.6
							H.T.A.	42,700	42,900	17,600	18,550	7.2	7.4	7.5
211A†	ASTM	Same as 208A, except	Wedge	1400	⅝	0.005								
A	4	natural gas added to	Test Bar			0.003	A.C.	30,800	31,150	15,150	15,150	5.4	5.8	6.7
B		melt at 1500° F.	Test Bar				H.T.	38,800	40,800	13,400	13,800	11.0	13.0	15.9
							H.T.A.	37,700	38,850	17,300	18,450	4.3	5.0	5.7

*Cleaned with No. 310 flux only.
**Mechanical properties based on results from two test bars.
†Carbothermic metal.

Table 7

Effect of Simultaneous Cleaning, Degassing, and Grain Refining with Cl_2-CCl_4 Mixture

Specimen No.	Alloy	Condition and Treatment	Castings Poured	Pouring Temp., °F.	Height of Sound Metal in Wedge, in.	Grain Size, in. × 10^{-3}	Heat Treatment	Mechanical Properties: Tensile Strength, psi. Min.	Tensile Strength, psi. Avg.	Yield Strength, psi. Min.	Yield Strength, psi. Avg.	Elongation in 2 In., per cent Min.	Elongation in 2 In., per cent Avg.	Reduction of Area, per cent Avg.
409A	ASTM-4	Cleaned with unfused	Wedge	1400	1½	15-30								
A		No. 310 flux.	Test Bar	1390		12-30	A.C.		24,800		11,300		4.4	3.1
							H.T.	31,400	32,200	11,000	12,700	5.7	7.3	9.3
B		Cleaned with Cl-CCl_4	Wedge	1400	2¼	6-8								
B		CCl_4 mixture, CCl_4	Test Bar	1390		6-7	A.C.		28,900		13,000		6.1	5.6
		in water bath at 70°					H.T.	39,800	39,900	13,200	13,200	12.5	12.9	15.0
		F. 0.03 lb. CCl_4 used.												
		Treated 15 min. at												
		1380-1430° F.												
410A	ASTM-4	Cleaned with un-	Wedge	1400	2									
A		fused No. 310 flux	Test Bar	1390		12-25	A.C.		27,600		11,900		5.7	5.5
							H.T.	33,000	33,600	11,400	12,400	8.8	8.9	10.7
B		Fluxed same as 409B,	Wedge	1400	2	5-7								
B		but water bath at 80°	Test Bar	1390		4-5	A.C.		28,100		14,200		4.5	4.3
		F. 0.22 lb. CCl_4 used.					H.T.	42,500	42,500	13,400	13,400	14.6	15.3	16.1
C		Held at 1400° F.	Test Bar	1400		7-8	A.C.		26,800		13,800		4.4	4.7
		15 min. after flux.					H.T.	38,600	39,200	12,100	12,700	11.4	11.9	13.8
411A	ASTM-4	Cleaned with un-	Wedge	1400	2⅜	25-5								
A		fused No. 310 flux.	Test Bar	1390		12-30	A.C.		26,300		11,400		4.8	5.6
							H.T.	27,200	29,800	11,000	11,000	7.9	10.0	6.2
B		Cleaned same as 409B,	Wedge	1400	3⅛	6-7								
B		except water bath at	Test Bar	1390		5-7	A.C.		26,100		14,300		5.0	4.8
		90° F. and 0.33 lb.					H.T.	37,900	38,300	13,200	13,400	11.6	12.1	13.8
		CCl_4 used.												
C		Held at 1400° F. for	Test Bar	1400		4-5	A.C.		28,600		14,100		5.4	6.7
		15 min. after cleaning.					H.T.	39,800	40,500	12,800	13,200	11.8	12.2	14.1

bon tetrachloride is rather fine, and much finer than the as-melted grain size reported in Table 7, these latter heats having been prepared from all new ingots none of which had been inoculated with carbon or carbon-containing materials.

Table 9 shows the effect of remelting ingots which had been poured from a melt treated with chlorine and carbon tetrachloride. The as-melted grain size is again moderately fine because this material also was 75 per cent scrap and 25 per cent new metal.

It will be noted that when the ingot is remelted and heated to and poured from a temperature of 1260° F., the grain size is rather coarse. As the temperature was increased, the grain size decreased, indicating that the grain-refining constituent was taken into solution, in which condition it could be an effective grain refiner.

The decreasing grain size with increasing temperature was effected without any stirring or other agitation of the melt. It also will be noted that as the melt was allowed to cool again, grain coarsening did not occur. This is attributed to the relatively short time required to cool the melt, a time period which is not sufficient to allow grain coarsening.

It may be concluded from this work that mixtures of chlorine and carbon tetrachloride have considerable practical possibilities in the foundry. While large melts of 2000 lb. have not been treated, it is quite likely that the method would be applicable to such large quantities of metal.

It is merely necessary to melt the ingot and scrap, using a small amount of flux to prevent burning during the melting operation. When the melt reaches a temperature of around 1300° F., it may be cleaned, degassed, and the grain refined during the heating-up operation by passing a mixture of chlorine and carbon tetrachloride through the melt by means of a carbon tube.

It is believed that high quality melts can be prepared in this way. However, it should be pointed out that there is a possibility of the melt being damaged during the transfer from the large melting furnace to the mold. Work on this problem has only begun.

One of the obvious objections to the use of chlorine and carbon tetrachloride mixtures is the toxic effect of these materials. Chlorine has been widely used in aluminum foundries in which the fume problem has been successfully handled.

Since the metal treatment is confined to a few large furnaces rather than to many small ones, it is believed that suitable hoods could be constructed over the tilt furnaces to carry away the fumes, and that the resulting atmosphere in the melting room might be somewhat superior to that now existing with present commercial methods.

There are many materials which, if added to pure magnesium, will produce considerable grain refinement. Commercially pure magnesium tends to be very coarse-grained, frequently of a long columnar form. The addition of either zinc or aluminum, particularly aluminum, will cause a very substantial decrease in the resulting cast grain size.

Similar effects are common among all cast metals. These effects might be regarded as gross grain refinement. However, when additional grain refinement of these alloys is attempted, the problem becomes considerably more difficult. There is some evidence that effective grain refiners in aluminum-base materials have limited solubility in the solid state and are characterized by a very steeply rising liquidus line, beginning very near the aluminum end of the diagram.

It is quite possible and entirely logical that effective grain refiners of cast materials must have slight solubility in the liquid metal. Apparently, also, this grain-refining

Table 8

EFFECT OF HOLDING MELT AT VARIOUS TEMPERATURES AFTER Cl_2-CCl_4 TREATMENT AT 1400° F., AND EFFECT OF REHEATING TO 1450° F. AFTER HOLDING MELT AT VARIOUS LOWER TEMPERATURES

	After Melting — Wedge Data			After Cl_2-CCl_4 Treatment — Wedge Data				Grain Size of Test Bar After Holding			After Holding 3 to 4 Hr., Reheating to 1450° F., and Stirring Gently — Wedge Data		
No. of Heats	Height of Sound Metal, in.	Grain Size, in.	Test Bar Grain Size, in.	Height of Sound Metal, in.	Grain Size, in.	Test Bar Grain Size, in.	Holding Temp., °F.	15 Min.	½-1 Hr.	2, 3 and 4 Hr.	Height of Sound Metal, in.	Grain Size, in.	Test Bar Grain Size, in.
4* Min.	⅜	0.004	0.004	2¼	0.005	0.004	1230	0.006	0.008	0.010	2½	0.005	0.004
Max.	2½	0.006	0.005	2¾	0.010	0.008	to	0.015	0.015	0.030	3½	0.007	0.005
Avg.	1½	0.005	0.004	2½	0.007	0.006	1260	0.010	0.011	0.016		0.006	0.004
4* Min.	⅜	0.005	0.004	2¼	0.006	0.004		0.004	0.003	0.004	3¼	0.005	0.004
Max.	1⅛	0.008	0.010	3	0.012	0.006		0.010	0.010	0.010	3½	0.006	0.007
Avg.	1½	0.007	0.007	2⅝	0.009	0.005	1300	0.006	0.005	0.007	3⅜	0.005	0.005
4* Min.	0	0.004	0.004	1¾	0.005	0.004		0.003	0.003	0.004	2⅜	0.004	0.004
Max.	⅛	0.008	0.010	2⅝	0.007	0.007		0.005	0.008	0.010	2⅝	0.006	0.006
Avg.	0	0.006	0.007	2⅝	0.006	0.005	1400	0.004	0.0045	0.0055	2½†	0.005†	0.004†
4* Min.	0	0.005	0.005	2	0.005	0.003		0.004	0.004	0.004	2	0.003	0.003
Max.	¾	0.007	0.006	2¾	0.010	0.006		0.007	0.008	0.008	2½	0.008	0.006
Avg.	¼	0.006	0.0055	2⅜	0.008	0.005	1500	0.0055	0.0055	0.005	2¼	0.0075	0.004

*One heat each of ASTM-4, ASTM-17, A-8, and AZ-91 alloys, using 25 per cent new ingot and 75 per cent scrap formerly treated with carbon-containing materials.

†Stirred gently 3 min.

constituent which is in solution must precipitate out of the melt early in the process of solidification, supplying a cloud of nuclei around which the cast grains grow.

The greater the number of nuclei supplied, the finer the grain size produced. It is not necessary that the active grain-refining constituent decompose; it merely precipitates from the liquid solution at the proper temperature to form the nuclei for the later crystals produced during the solidification of the melt.

Aluminum Carbide

This conception of the grain-refining carbon action is consistent with most, or all, of the observed experimental facts. It has been noted that carbon and aluminum are necessary before grain refinement is obtained. It is suggested, therefore, that the active grain-refining constituent is aluminum carbide.

There is, of course, a possibility that the aluminum does not occur in the active grain-refining constituent. It is conceivable that the aluminum merely changes the solubility of the active constituent so that it precipitates from the melt in sufficient quantity at the correct temperatures to produce maximum grain refinement.

It is more logical, however, to assume that the aluminum is a part of the active grain-refining constituent with the carbon in the form of aluminum carbide.

If the foregoing description of the mechanism of grain refinement with carbon in magnesium alloy melts is correct, it accounts for the following experimental facts:

1. The grain is coarsened by holding the melt at low temperatures. When the melt is held at a temperature near 1250° F., the aluminum carbide is precipitated and, when the time is sufficient, these particles either settle out or coagulate, thereby reducing the number of nuclei per unit of volume of melt and, consequently, increasing the grain size when the melt solidifies.

2. After holding at a low temperature and then reheating, grain refinement is restored. When the melt is reheated after it has been permitted to stand for a few minutes or several hours at a temperature of 1250° F., the coagulated nuclei are redissolved and the effectiveness of the grain-refining action of the carbon is nearly as great as ever.

Since it is not necessary to stir the melt after the holding period at the low temperature, but merely necessary to reheat it, it is concluded that the aluminum carbide is precipitated and coagulated but does not actually settle out completely.

If it did settle out completely, it is logical that some stirring would be essential before effective grain refinement would be restored. However, it has been noted that gentle stirring aids the restoration of the grain refinement, and it is concluded that the coagulated nuclei do tend to settle slightly.

3. As the temperature of the holding period increases, the grain coarsening produced by the holding decreases. The reason for this obviously is that the higher the holding temperature the less the precipitation of the aluminum carbide, and consequently there is less coagulation of the grain-refining constituent. Most of the grain-refining constituent remains in solution where it can effectively refine the grain when the melt solidifies.

4. When a melt is treated with

Table 9

EFFECT OF REMELTING INGOT FORMERLY TREATED WITH Cl_2-CCl_4**

Condition	Wedge Data — Height of Sound Metal, in.	Wedge Data — Grain Size, in.	Test Bar Grain Size, in.
As melted, 75 per cent scrap	¼	0.006	0.004-0.005
Treated with Cl_2-CCl_4	2⅛	0.006-0.007	0.006-0.007
Pigged, remelted only			
Poured at 1260° F.			0.008-0.10
Poured at 1350° F.			0.004
Poured at 1450° F.*			0.003-0.004
Poured at 1350° F.			0.003
Poured at 1250° F.			0.003

*The pouring temperature is also the maximum temperature except for 1450° F., the maximum temperature in this case being 1480° F.

**Melt was not stirred when the ingot was remelted

the chlorine - carbon tetrachloride mixture and the grain refined thereby, the melt pigged off and the ingot remelted, the grains are coarse at the low pouring temperature, but as the temperature increases the original grain refinement is again obtained. When the melt was pigged off, the aluminum carbide, of course, precipitated.

Effect of Remelting

When the metal containing this finely divided suspension of aluminum carbide is again melted, some coagulation occurs at low temperatures, thus causing a coarse grain. However, when the temperature is increased, even without stirring, more of the aluminum carbide is taken into solution, and the grain size gradually decreases as normal foundry pouring temperatures of 1400-1470° F. are reached.

5. When the melt is treated with the carbon-containing gas at a low melt temperature near 1250° F., the grain-refining effect is not very marked because the solubility of the aluminum carbide is too low at this temperature. If, however, the melt treatment temperature is increased to near 1400° F., the temperature is sufficiently high to produce adequate solution of the aluminum carbide constituent and thereby obtain good grain refinement upon solidification.

6. Solid carbon-containing materials are not always effective because it is too difficult to obtain sufficient solution of the carbon portion of the material.

Carbon in Atomic Form

Organic chlorides are especially effective because the vapor from the organic chloride combines with the magnesium melt, forming carbon in an atomic form and magnesium chloride. The carbon in atomic form is in an ideal condition for solution in the melt. Consequently, this method of grain refining is invariably effective and reliable.

7. The fact that carbothermic metal tends to be finer grained than electrolytic metal can be attributed to the higher carbon content of the former.

8. It has been noted that quite frequently very coarse grains are obtained at a pouring temperature near 1250° F. However, in some instances, fine grain is obtained at low pouring temperatures.

Apparently the important factor

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is the amount of time the melt is maintained at the low temperatures before it is poured into the mold. If cooling is fairly rapid, coagulation of the precipitated aluminum carbides does not occur when the low pouring temperature is reached and fine grains result.

Cooling Rate

If the cooling rate of the melt near the pouring temperature is very slow, coagulation of the aluminum carbide does occur, and a coarse grain is produced when the melt solidifies. All melts, of course, pass through this range when they are poured into a mold and solidify.

The time lapse, however, is generally very short and no coarsening occurs. Consequently, if low pouring temperatures are used, it is necessary to cool to these temperatures fairly rapidly. Otherwise, grain coarsening will occur. This is probably the reason that large melts are difficult to superheat in the foundry because the cooling rate of the large melt is too slow to maintain the grain-refining effect.

Low pouring temperatures are not ordinarily encountered in foundry operation. However, in ingot and billet casting shops, low pouring temperatures and large melts are used, and it is under these conditions that considerable variation and trouble can be encountered because of the adverse effect of slow cooling upon the effectiveness of any grain-refining operation which is attempted. Of course, some wrought alloy compositions are not amenable to any known grain-refining procedure.

Superheating Function

The behavior of the superheated metal has not been investigated, in a systematic manner, in this work. Consequently, it is somewhat hazardous to suggest that the function of superheating is essentially the solution of the grain-refining constituent, probably aluminum carbide.

Superheated melts have characteristics very similar to those which have been inoculated with carbon at lower melt temperatures than those used for superheating. Apparently, however, superheated melts coarsen at somewhat higher temperatures.

The grain size produced by superheated melts is more adversely affected by holding at intermediate temperatures than are melts which have been inoculated with carbon. If the grain-refining effect obtained by superheating is due to solution of aluminum carbide, there is no apparent reason why superheated melts should not perform exactly the same as melts which have been inoculated with carbon.

Since no definite measures are taken to subject the melt to a carbon source at the superheating temperatures, it is quite logical that some variable results might be obtained with the superheating operation, some melts being much more amenable to grain refinement than others.

Refining Flux

Commercial fluxes used for melting magnesium usually contain carbon, and some grain refinement is obtained by the usual cleaning operation with the refining flux. However, the melt temperature for this treatment is on the low side for effective carbon absorption.

Even melts of magnesium produced by the electrolytic process contain some carbon. In any event, it would be expected that there would be sufficient carbon present in the flux, pot, or metal to produce grain refinement by carbon absorption when subjecting the metal to a high temperature.

In this connection, it should be noted that long exposures to high temperatures during the superheating operation sometimes actually produced grain coarsening. This has not been checked with carbon inoculation, but it is quite possible that the same effect could be observed.

This phenomenon could be explained as follows: The long time at a very high temperature gives ample opportunity for a high degree of solution of carbon in the melt.

When the melt is cooled, the aluminum carbide precipitates out of solution at too high a temperature because of the high concentration of this constituent. This condition would favor coagulation of the precipitated grain refiner, producing coarse grains when the melt solidifies.

A method of producing high quality magnesium melts has been de-

scribed in a separate paper.[5] As a part of this general program, this paper describes a method of obtaining grain refinement in the melt cleaned and degassed by the new method.

Summary

In general, magnesium alloy melts containing aluminum can be treated to produce grain refinement by using a carbonaceous material, which may be a carbon-containing gas, such as dry natural gas, a solid such as graphite or aluminum carbide, or a vapor from an organic chloride.

The carbonaceous gas is as effective as superheating, but there is the danger of regassing the melt if this gas is not dry, and the method is slightly awkward and time consuming. The carbonaceous solids are generally effective, although the results are sometimes erratic because of the difficulties of obtaining proper solution of the carbon from such materials.

The organic chlorides are very reliable, give good grain refinement, and also provide some cleaning and degassing effect normally obtained with chlorine.

It has been found that a mixture of chlorine and carbon tetrachloride obtained by bubbling the chlorine through a bath of the liquid tetrachloride effectively and reliably degasses, cleans, and produces grain refinement in one operation.

This procedure has been very successful on melts weighing up to 120 lb. It is believed that the method is applicable to the large melts which might be obtained in normal foundry operation, such as those prepared in a 2000-lb. tilt furnace.

Recommended Temperatures

Proper methods of transferring this melt to the mold, either directly or by way of a ladle, are being investigated. Temperatures of around 1350-1450° F. are recommended for treatment with the chlorine-carbon tetrachloride mixture.

The grain size of castings poured from such melts is increased by holding the melt near a temperature of 1250° F. This adverse effect on grain size gradually decreases with increased temperatures until at 1400° F. only a very slight coarsening occurs after several hours at this temperature.

The grain-refining effect which is lost by holding at low temperatures is restored by simply reheating to 1400-1450° F. It has been found that there is a considerable carry-over of grain refinement when such metal is remelted, the grain size gradually decreasing as the maximum temperature and pouring temperature approaches 1450° F. It is quite possible, however, that for reliable grain refinement, each melt should be treated and the carry-over from the preceding treatment should not be relied upon.

A general theory of the mechanism whereby the carbon inoculation produces grain refinement has been described. It is suggested that aluminum carbide, Al_4C_3, is the active grain-refining constituent, and this compound is dissolved in the melt.

When the melt is cast, the aluminum carbide is precipitated near or slightly above the liquidus line at which solidification begins, producing a cloud of nuclei around which the individual grains form. The greater the number of nuclei per unit of volume of melt, the finer the grain which is produced.

Acknowledgment

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NON-DESTRUCTIVE TESTING
of Steel Castings

Report of the Steel Division Committee of A.F.A.

● Methods developments and progress in setting up standards for non-destructive testing are reported to members of A.F.A. Steel Division. The bibliography of recent publications contains articles on non-destructive testing of steel castings, technique and fundamentals related to radiography of steel castings.

DURING the year from April 1944 to April 1945 the A.F.A. Steel Division Committee on Non-Destructive Testing took an active part in matters connected especially with the magnetic particle testing of steel castings. One member of the committee, A. P. Spooner of Bethlehem Steel Co., took the lead in arranging and preparing the drafts on a standard practice for magnetic particle testing which was submitted to the American Society for Testing Materials. All the members of the A.F.A. committee were asked to review the drafts and submit comments. The material so prepared has been set up as a standard procedure specification E-222 of the ASTM. It is the belief of your committee that this procedure is an excellent one and will better enable steel foundries to carry forward their studies in connection with non-destructive testing. Those foundries that have not as yet entered the magnetic powder inspection field would do well to study the procedure of E-222, as it is believed that they will be materially benefited by this clear and authoritative recommended procedure.

The committee realizes that its review by questionnaire of the status of the use of non-destructive testing in the steel casting industry is long overdue. However, in view of the production requirements for steel castings during the past year as a result of the war, it was deemed advisable to again postpone asking the foundries to execute a long questionnaire on the subject of non-destructive testing. This study will be undertaken at the first opportune moment.

The committee is of the opinion that the use of non-destructive testing methods has reached a new high in the steel casting industry during the past year. In fact, it would be used to even greater extent than it now is, if a greater supply of radiographic film were available.

There have been no new developments during the year in radiographic standards. Committee E-7 of the ASTM has not as yet come forward with radiographic standards. This committee has, however, clarified its definitions regarding the appearance of defects as illustrated by radiography.

During the 1944 A.F.A. Annual Meeting, two excellent papers on non-destructive testing were presented by J. F. Cotton and P. Ffield of the Bethlehem Steel Co. It was planned to hold a symposium on non-destructive methods at the 1945 A.F.A. Annual Meeting. This symposium was not held owing to the O.D.T. restriction on meetings; however, all the papers scheduled for presentation will be published in A.F.A. publications.

In line with the policy established during the past two years, this report presents a review of only those articles the subject of which is related to the non-destructive testing of steel castings. These articles are listed as an appendix to this report.

COMMITTEE ON NON-DESTRUCTIVE TESTING

C. W. Briggs, *Chairman*
R. A. Gezelius, *Vice-Chairman*
Philip De Huff, Jr. — A. P. Spooner
John W. Juppenlatz — R. H. Frank
Werner Finster — L. W. Ball

Appended Bibliography on Non-Destructive Testing

Articles on the Non-Destructive Testing of Steel Castings

1. J. F. Cotton, "Magnetic Powder Inspection of Large Castings," TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 205-231 (1944). A quantitative evaluation is given of the variables which govern magnetic powder inspection. The evaluation shows that a standardized technique must be established before standards of magnetic powder inspection can be prepared.

2. P. Ffield, "Conditioning of Steel

Booths for production radiography of large steel castings. Note concrete walls to avoid fogging of films on adjacent castings.[2] (Right)—Magnetic particle inspection (prod method) of large casting using special wet battery. (Left)—Applying powder. (Right)—Checking current.[2] *(Courtesy Bethlehem Steel Co.)*

Castings to Standards of Quality," TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 173-204 (1944). Application of non-destructive tests; influence of non-destructive testing on the conditioning of castings; radiographic standards of acceptability; practicability and interpretations of magnetic powder standards; significance of cracks in high-pressure, high-temperature castings; magnetic powder inspection as a complement to radiography; flame excavation of defects; magnetic inspection of flame-gouged areas.

3. C. L. Frear, "Radiographic Specifications and Standards for Naval Materials," TRANSACTIONS, American Foundrymen's Association, vol. 52, pp. 1078-1110 (1944), and *Industrial Radiography*, Spring, 1944, pp. 33-36. In a summary of the inspection by the Navy, the history of its use as a means of inspection is presented. A list of the different classes of castings requiring this inspection is given, also the influence of the requirement upon the steel foundry industry. The specific requirements of the Navy, process approval and radiographic standards are discussed. A table of radiographic standards is included.

4. R. Taylor, "Radium Radiography in Industry," *Steel*, April 10, 1944, pp. 108, 110, 112. A review of the use of radium in the inspection of castings that are to withstand high pressure and temperatures, such as steam boilers, marine equipment, hydraulic power installations; also for the inspection of pilot castings. Two methods for industrial use are described.

5. R. Taylor, "The Value of Radiographic Inspection to the Small Foundry," AMERICAN FOUNDRYMAN, May, 1944, pp. 2-4. A discussion of the value of this method of inspection as a cost saver in the small foundry. As the value of the method is not limited to the detection of imperfect castings, it can be used as a means of improved foundry control for the production of sound castings.

6. "Two Million Volt X-ray Tube for Thick Steel Sections," *The Iron Age*, Nov. 2, 1944, p. 62. Description and photograph of the 2-million volt x-ray tube with which heavy steel objects up to one foot in thickness can be radiographed with relatively short exposures.

7. C. L. Frear, "Magnetic Powder Inspection of Castings," ASTM Bulletin, Dec., 1944, pp. 12-14. The use of magnetic powder inspection on valves and fittings, and hull castings. A discussion of the interpretation of indications shown by various casting defects, magnetic powder procedure for steel castings, magnetizing equipment, and magnetic powder versus radiography.

Articles on Technique and Fundamentals That Are Related to Radiography of Steel Castings

1. A. Morrison and E. M. Nodwell, "Exposure Graphs for Radium Radiography of Steel," ASTM Bulletin, March, 1944, pp. 25-30.

2. A. Morrison and E. M. Nodwell, "Use of Film to Measure Exposures to Gamma Rays," ASTM Bulletin, March, 1944, pp. 31-32, and *Industrial Radiography*, Summer, 1944, pp. 31-32.

3. S. Maddigan and B. Zimmerman, "Microradiography—A New Metallurgical Tool," *Metals Technology*, Feb., 1944, TP 1683, 26 pp.

4. "Co-Operative X-ray Research," *Steel*, March 20, 1944, p. 96.

5. R. Taylor, "Radium Inspection of Metals," *Steel*, April 3, 1944, pp. 122, 124, 166, 168, 170.

6. R. Taylor, "X-ray Process Engineering," *The Foundry*, May, 1944, pp. 74, 141-142.

7. G. Close, "Organic Coating Aids Magnetic Inspection," *The Iron Age*, Aug. 31, 1944, p. 4.

8. C. Jenni, "Stopper Heads X-rayed to Eliminate Pouring Trouble," *The Foundry*, Sept., 1944, pp. 68-70, 208.

9. L. W. Ball, "Radiographs—What They Tell Designers," *Machine Design*, Dec., 1944, pp. 135-140.

10. Symposium on Magnetic Particle Testing: A. V. de Forest and C. E. Betz, "Equipment for Magnetic Particle Inspection." H. H. Lester, "Magnetic Particle Inspection, Particularly from the Standpoint of Specification Requirements." E. O. Dixon, "Magnetic Particle Inspection of Aircraft Parts." L. B. Jones, "The Magnetic Particle Test as Utilized by the Railroads." A. P. Spooner, "Specifications and Procedures." C. L. Frear, "Magnetic Powder Inspection of Castings." C. J. Boyle, "Magnetic Particle Inspection of Forgings." E. A. Snader, "Miscellaneous Applications of the Magnetic Particle Test." ASTM Bulletin, Dec., 1944, pp. 7-16.

11. L. W. Ball, "Interpreting Aircraft Radiographs," *The Foundry*, Feb., 1945, pp. 82-85, 192, 194, 196, 198.

12. J. Bland and E. Banks, "Adjustable Radium Capsule Support," *Industrial Radiography*, Winter, 1944-45, pp. 23-25.

13. E. Meschter, "A Simplified Method of Film Evaluation," *Industrial Radiography*, Winter, 1944-45, p. 35.

Other Non-Destructive Methods of Testing

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• Agreement upon standards for interpretation of defects revealed by non-destructive testing methods is the controlling factor in the value of these methods as a test means. Workable standards, based upon the essential service of the material tested, should provide for ready definition into acceptable and non-acceptable classifications.

THE subjects, radiography and magnetic particle inspection, cover two basic, well-known and reasonably well established methods of non-destructive testing. First, the radiography method may be applied to diversified castings of any metallic composition, with x-ray fluoroscopy for sections of low density; second, the magnetic particle test is limited to and can be applied only to magnetic materials, diclosing defects at and near the surface.

Other methods of non-destructive testing, applicable to castings, have proved to be of practical importance, with still others in the process of experimental development. Several of these methods are used as independent tests but employed as supplemental aids to radiography. Some of the better known methods will be briefly considered in the following discussion.

Penetrant Materials

For many years foundries have recognized the value of applying a light machine oil to the surface of castings, allowing time for its penetration into surface defects, then removing the excess surface oil with a light sand blast. This leaves the surface with a light colored silica dust on all areas except those containing defects such as cracks and surface imperfections, which are soon discolored by oil returning to the surface.

This method is a deviation of the well-known "whiting" method. Further development employs the use of a fluorescent penetrant on castings, with the subsequent examination made under ultra-violet light. This method was publicized by T. DeForest in 1942[1], and since then by others.

The fluorescent method, developed by the Switzer brothers with patent application in 1938, is obviously more sensitive than the whiting method and has become a reasonably well established method of non-destructive testing for foundry inspection. It is not limited to size of casting nor type of analysis. However, defects must be of surface origin for detection. Subsurface defects are not disclosed. Internal shrinkage may be indicated only when the defect is continuous to the surface of the casting.

Application Range

The application of this penetrant fluorescent method is not confined to non-magnetic castings. Results compare favorably with the magnetic powder test in disclosing defects that are apparent on the surface; however, it does not indicate slight subsurface defects, even though this defect is a continuation of the apparent surface defect, such as often experienced with the magnetic particle test.

Demagnetization of castings, which is occasionally necessary when using the magnetic particle test, is not required. The penetrant fluorescent method is often used on castings where intricate shapes of magnetic castings causes difficulty in the introduction of the required magnetic-flux-density.

The process, equipment and materials for the penetrant fluorescent inspection of castings is comparatively simple. The first requirement is the preparation of the casting, which should be well cleaned of such surface irregularities as tend to form extraneous cavities, including sand or scale.

The casting may be immersed in a tank containing a light penetrating oil chemically treated for high fluorescent brilliance and water solubility. In lieu of dipping, the oil may be brushed or sprayed on the casting surface, but when size permits, total immersion is preferable. Ten min. time of immersion for oil penetration is considered sufficient for most applications.

Excess oil is allowed to drain from the castings for re-use. The adhering surface oil must be washed off, preferably by clean, hot water. Emulsifying action of the water is greater when hot, and a nozzle effect aids in the surface cleaning of fillets, etc. A water dip, followed by a spray rinse, leaves the surfaces smudgy and is not recommended. With the castings warm from the hot water rinse, air drying is quickly accomplished and the casting is soon ready for inspection.

Examination Conditions

Castings may be inspected immediately, but are preferably given sufficient time for the penetrant to return to the surface in case defects are present. A darkened room is required for visual examination under "black light" or near ultra-violet light which is not registered by the human eye.

After a few minutes for adjustment of the eye, defects appear to fluoresce where the penetrant oil has returned to the surface. Depending upon the time elapsed from rinse to examination, an experienced operator can distinguish the relative form and dimension of the defect by the amount of penetrant being ejected to the surface.

An alternative method of process-

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ing employs the use of an absorbent developing powder which is applied to the casting surface in excess after the normal hot water rinse. This developing powder tends to draw the penetrant from the defects and cause a higher degree of contrast between the defect and the background. This method is not generally used on as-cast surfaces, since it is an additional operation which does not appear to aid in disclosing real defects.

Inspectors soon become trained to visually distinguish between defects and what might be termed blemishes or surface sand particles which might trap some penetrant. On the other hand, cracks or other significant defects are very apparent. These defects, after being located and marked, can be removed by chipping or grinding.

Re-examination of Defect

When the chipper is not certain of complete defect removal, it is possible without any reprocessing to re-examine the casting defect under the "black light." If any portion of the defect remains, it will fluoresce as long as the penetrant remains within it.

Some of the advantages of this method of inspection are cause for its rapid gain in popularity. The operating cost of testing is low as compared to radiography. Equipment and materials are readily accessible without large expenditures. However, it is limited to disclosure of surface defects only.

By preliminary fluorescent penetrant inspection of castings, such defects as may be disclosed can be repaired before final radiographic examination, thereby saving considerable time and expense when a re-radiograph of the repaired casting is required. This method may disclose defects which are not indicated on radiographic negatives due to their size or direction. It therefore does not replace radiography, but supplements it.

Loading Tests

Static loading non-destructive tests of castings are commonly being applied to finished structural components to prove their suitability for the service intended. Many of the parts are subjected to predetermined live-load tests simulating service conditions, followed by measurement of the amount of deflection and permanent set when the load is released.

This type of non-destructive test determines not only the quality of material but is often used in the development of satisfactory designs. For proof tests, these parts are subjected to stresses well below the elastic limit, with the usual specifications not allowing any permanent deformation. Loading is usually one and one-half times or more than the maximum service loads, and this test segregates castings or designs with substandard strength.

Static proof testing is often applied to castings with known defects as disclosed by other methods of non-destructive testing. These castings are proof loaded, checked, and reloaded with increased loads until permanent set or destruction has occurred.

This information, coupled with actual service results, aids in establishing the permissible extent of casting defects allowable with some margin of safety. Location of defect with size, type and direction as disclosed by other non-destructive tests should be taken into account, thus forming workable standards of acceptance or rejection for the parts involved.

Testing Pressure Castings

Hydrostatic testing of pressure type castings has superseded practically all forms of non-destructive testing. It is being regularly applied as a final inspection method to fittings at standard pressures in excess of their normal working pressure, even though radiographic and other non-destructive tests have been applied. Air pressure tests, at pressures often greater than the working pressure, are common with the castings immersed in water.

An air test of unmachined pressure fittings is frequently applied in foundries, using a water-soap solution and observing any bubble formation indicating unsoundness. Likewise steam, cold and hot oil pressure tests are used. Any of these tests are for the purpose of segregating "leakers" or defects which pass from wall to wall of the casting.

Acoustic Tests

Acoustic tests, such as striking a casting with a hammer to determine if it "rings true," are old. A modification of this method includes the use of the medical stethoscope. The results of this test are largely dependent upon the operator's skill in making and receiving the vibrating sound waves that are only qualitative or indicative.

Supersonic Tests. Supersonic or ultrasonic waves with frequencies beyond the range of audible sound are reported to have been used for several years in Russia[2], Germany[3], and other countries[4].

The application of supersonics to castings in this country has been limited to special applications and could be generally expressed as being in the experimental stages. Obviously, this method can be further developed so as to be an important means of non-destructive testing.

Supersonics Development

A communication from R. H. Wallace (Sperry Products, Inc., Hoboken, N. J.) describes an American development of the supersonic reflectoscope for testing castings:

"In testing by means of the supersonic reflectoscope, supersonic vibrations are sent into the material under test by means of an ocillator with a pulse circuit which sends out "trains" of vibration. Each pulse of vibration penetrates the material and reflects from the opposite side or from intervening defects to re-energize the sending crystal which has ceased to vibrate during the period in which the pulse oscillator is not functioning. This reflection is then amplified and placed on an oscilloscope screen. Pulses are at a frequency of 60 per second and reflections are therefore superimposed continually at this rate on the screen and appear as a continuous picture, showing at the left of the screen the sending pulse and in sequence from left to right any reflections of the original pulse, with the time intervals, which can be calibrated directly in inches of penetration, being read directly off the screen. By the degree of absorption of these reflections in the various materials a relative indication of grain size is given.

"In the application of this equipment to castings the grain size and porosity play a limiting factor, since the larger these are the greater will be the absorption of the vibrations and the resultant difficulty in penetrating the material. In most cases, however, ample penetration can be obtained if the defects which it is desired to find are not too small.

For accurate determination of whether the reflectoscope can satisfactorily test castings, it is necessary to consider each application individually as to its shape, surface condition and absorption to supersonic vibrations. The size of defect which can probably be detected can then be predicted with reasonable accuracy.

"In applying the reflectoscope to a test piece, a flat or curved crystal is placed against the material with a film of oil in the inner face to improve the transmission of the vibrations. In some applications the "as cast" surface is sufficiently smooth but in others it would be necessary to use a small hand grinder to smooth off the rough spots."

According to A. Behr[4], the supersonic method in foreign countries has reached an advanced, although by no means, a final stage of development. Also, that the outstanding merit of the ultrasonic method is undoubtedly its ability to disclose defects which do not represent a sufficient change in "density" to enable their detection by x-rays.

Thus, cracks or lamination situated in a plane at right angles to the supersonic beam can be detected with certainty. Another advantage is the ability to deal with cross-sections of metal which could not be penetrated by x-rays or even gamma-rays.

The principle feature which hinders the development of supersonics for castings is the present difficulty of interpreting the results with certainty. Available equipment is highly sensitive to surface irregularities and minute blemishes. When these difficulties are overcome, this instrument may gain in use and popularity for non-destructive testing.

Other Electrical Methods

Other electrical methods of flaw detection in castings have been tried with limited application and degree of success to castings. One method involves the direct passage of current through the casting by brush contact and the measurement of the surrounding field set up by this current, similar to railroad rail inspection (Sperry). This electromagnetic method is limited to uniform longitudinal sections and does not lend itself to castings with variable or diversified sections.

Another electrical method, applicable to magnetic or non-magnetic materials, is the induction of current to its saturation point if magnetic, or partial saturation if non-magnetic, and measuring variations in the field as set up by this induced current. This method discloses flaws or changes of metal sections and is now commonly applied to bar stock or tubing as acceptance methods, but not to general castings due to variation of design.

Analysis and Structure

Still other electrical methods have been developed utilizing electrical principles, one of which employs a direct current in testing the thickness of a casting wall from one side only[5]. The potential drop caused by the flow of current is used to indicate wall thickness. These electrical methods require standard pieces of similar design with complete soundness for comparison. Due to diversified casting sections, this method of non-destructive testing remains limited.

Reference to methods of non-destructive testing for the purpose of segregating materials of varying analyses and states of heat-treatment should be included since such methods are in practical use for castings, but are not employed for the purpose of disclosing defects or flaws.

One of these instruments is based upon the principles of thermo electricity[6]. This test makes use of a known test piece, which is set up as one side of the circuit and in contact with an unknown test sample involving the other side of the circuit so that there is a mutual point of contact. With auxiliary electrical current input, the temperature at the point of contact increases, and if the metals are dissimilar, an electromotive force will be indicated on the instrument.

The test pieces act as the thermocouple and the instrument as the galvanometer. Materials have been segregated and checked for similarity of analysis, as well as conditions of structure and heat treatment. The process of test is quite simple and requires only a piece of known material for comparison. Its use on finished articles may be objectionable due to occasional marks of electrical contact.

The cyclograph[7], an electronic instrument, utilizes the principle of varying metallurgical properties which cause variation in the core loss

A development in the supersonic method of testing.

of a tuned pick-up coil which surrounds the piece under test. This variation affects the shape of the visible pattern or cyclogram displayed on cathode ray tube indicator screens. This instrument, while in the stages of development, refinement and practical application, is limited to uniform casting sections which can be inserted into a suitable test coil.

Standardization of cyclograph patterns with known materials can easily be made so that analysis and condition of heat treatments of identical production shapes can easily be checked for uniformity. Differentials of analysis, structure, depth of hardness or variables of heat treatment now are being checked with this method on malleable iron and steel castings.

The development of a suitable test coil for general casting inspection would permit wider application and use of this electronic method for inspection of finished castings in lieu of some of the testing methods being applied which could be classed as destructive tests. This instrument is not appreciably affected by casting defects and therefore is not recommended for that purpose.

Summary

The limiting factor controlling the use of non-destructive methods of testing for castings involves the correct interpretation of the results. Any method, in order to be practical, must be accepted by the foundryman. It should not reveal false indications and should be capable of readily defining defects into acceptable or non-acceptable classifications without too much controversy.

Standards of acceptance are becoming more critical with time and inspection methods are constantly being improved, such as witnessed by radiography within the past decade. Therefore, before any non-destructive method of testing for castings is established as a test means, a set of workable standards should be agreed upon which distinguish between flaws or blemishes and real defects which may affect the ultimate service of the casting.

Some deviation from casting perfection is unavoidable, and any method of non-destructive testing can survive only when proper emphasis is placed upon working standards and with due regard to interpretation based upon essential requirements.

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PATTERN and Allied EQUIPMENT

Design, Redesign and Interchangeability

By William E. Tharp, Foundry Technical Supervisor,
Caterpillar Tractor Co., Peoria, Ill.

• Designing engineers are weighing the advantages and disadvantages of foundry products as compared with the products of competitive processes. Lower cost per unit is the foundry's greatest asset. To maintain this cost advantage in the face of improved methods in other processes, the foundry must develop methods to produce castings at lower costs and to closer tolerances. Close cooperation between the casting designer and the foundryman, to obtain greater casting accuracy and lower costs through correctly designed patterns and the use of interchangeable pattern and other equipment, is a factor for the foundryman's careful consideration.

IT WAS NOT until centuries after the discovery of enduring metals, and the forming of parts therefrom, that the pouring of molten metal into a sand or clay mold was successfully accomplished.

The first parts to be made from metals were not poured. They were hammered into shape from a semi-molten mass of metal. This method of producing metal parts, with a few exceptions in bronze, existed for centuries.

It was not until the eighteenth century that man conceived and mastered the art of casting molten metal into a sand mold. Due to the demand for duplicate parts, he found that a pattern would be necessary. This pattern was made by the early foundryman himself, who must necessarily have been a smith or a metals craftsman.

The only reason for relating this thumb-nail history of castings and patterns is to impress upon the reader that patterns, in their infancy, were designed and, in most cases, made by the foundryman himself.

In later years, because of an increased demand for castings, it became necessary for the foundryman to hire craftsmen, who worked chiefly with wood, to make patterns for him. Even then the foundryman had to advise the craftsman in matters of moldability, but as the years passed the foundryman gained more and more confidence in his hireling and relinquished the greater part of the responsibility for the design of the pattern to the now titled pattern-maker. The results of this shift in responsibility are obvious in most, and possibly all, foundries today.

The fact that many patterns are poorly designed and are, therefore, responsible for a greater cost per casting, or a greater scrap percentage than should be necessary, should be a warning that the responsibility for the design of all patterns not only should be assumed but exercised by the foundryman.

A close follow-up with the pattern-maker should necessarily be maintained in order that small but harassing details, such as correct flask size, proper draft, correct partings of patterns and core boxes, correct placement of patterns in flask for proper gating, venting and wiring of cores, sturdy core driers, etc., are cared for in advance.

To say that correct pattern design is an art would be an understatement. It is both an art and an engineering achievement. A pattern, whether large or small, of wood or metal, can be designed in many different ways, and a casting derived from each could check just as dimensionally accurate from one as from another. Yet one design would stand out in the critical eyes of the foundryman as being most adaptable to his individual conditions.

Good proof of the foregoing statement is found in the entries by ap-

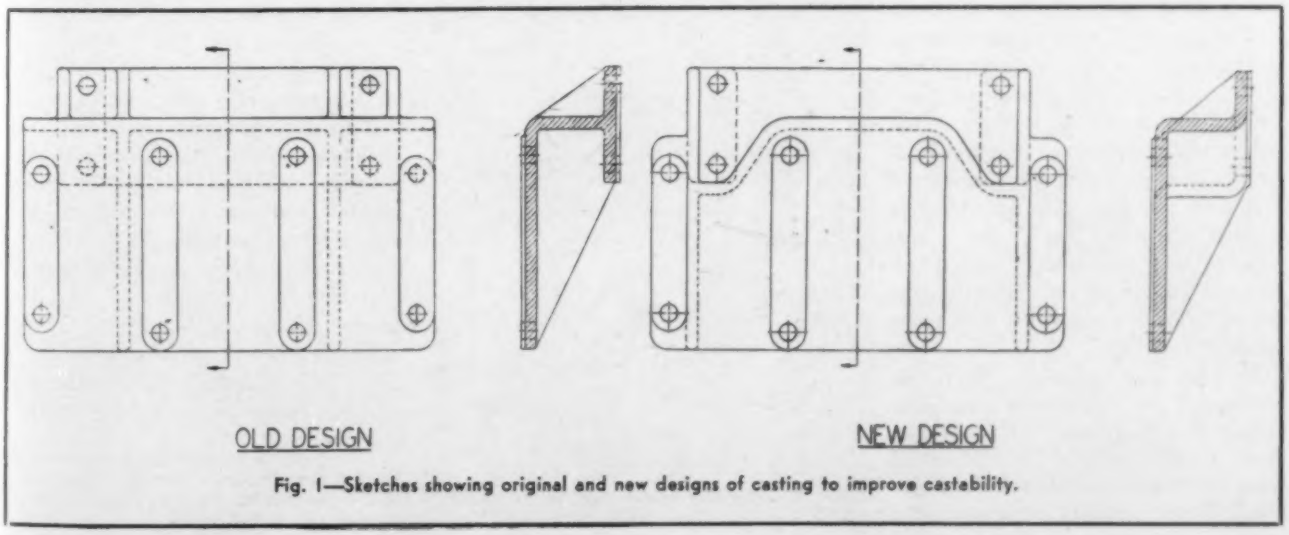

Fig. 1—Sketches showing original and new designs of casting to improve castability.

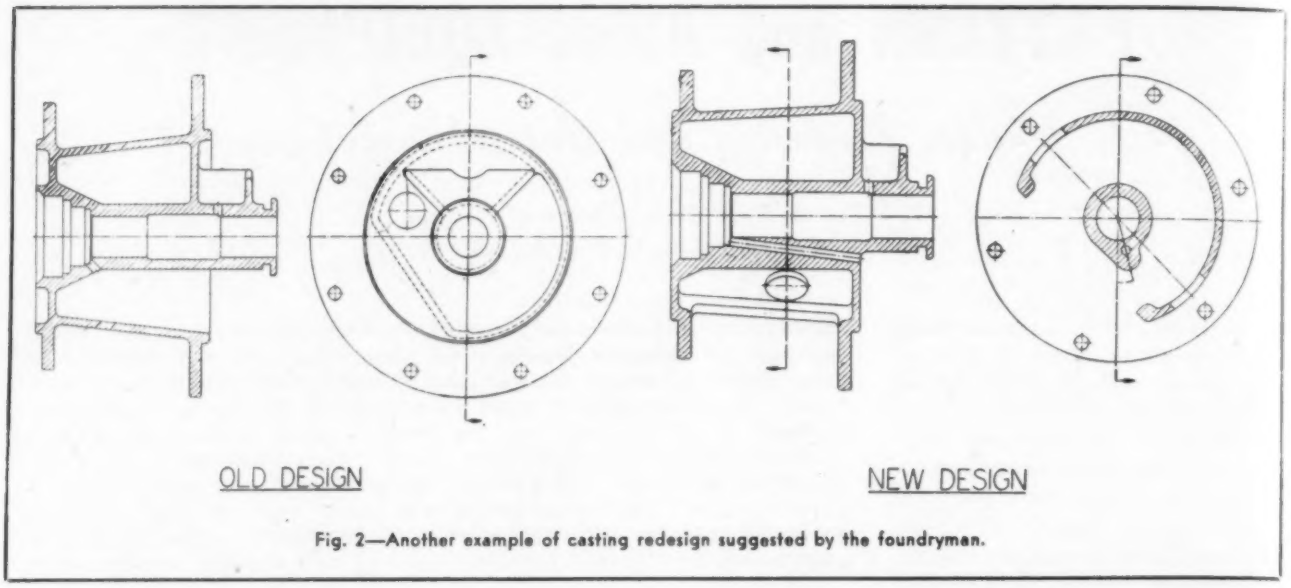

Fig. 2—Another example of casting redesign suggested by the foundryman.

prentices from all sections of the country of patterns in the A.F.A. National Apprentice Contests held in past years. It is very seldom that two of these contest patterns are designed alike. The winning pattern is chosen with moldability as being one of the main requisites.

The author might make the suggestion that moldability should be the main requisite, in order to impress future patternmakers with the importance of presenting a good, sound pattern design to the foundryman.

To design a pattern of flawless workmanship, at a low cost, accurate to perfection, only to find that it is difficult to make the core and assemble it, to make the mold at a proper rate of production, to gate properly, or to clean economically, definitely would be a waste of expensive material and man hours as far as the foundryman is concerned.

The foundry's most potential competitor today is the welding process. It is true that the foundries have proved to Army and Navy Ordnance and Engineers on several occasions that a casting is less expensive and more durable than a welded or riveted assembly. It is also a significant fact that many "would-be" castings are being satisfactorily produced from formed rolled steel parts welded together.

People who produce parts by welding have established and publicized four freedoms: 1. Freedom from excess weight. 2. Freedom from structural weakness. 3. Freedom from design improvements. 4. Freedom to use new materials where they are best suited.

This is indeed proof that the welding crafts are hoping that a good percentage of castings may in the future be lured out of the foundry and into a welding shop.

How can the foundries combat this migration? They can, and must, produce a lower cost product with equal qualifications. In order to produce castings at a low cost and at a low scrap percentage, methods and operations should be as simple as possible. The design of the pattern should be near perfection.

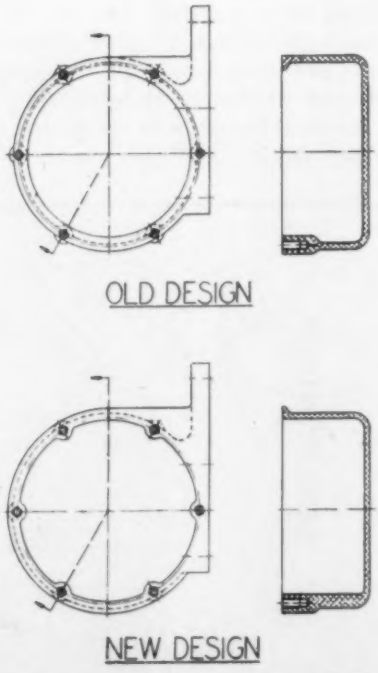

Fig. 3 — Casting redesigned to facilitate production.

In order to attain this Utopia, and it is possible, the foundryman must incorporate a pre-pattern planning and design department, or, of course, do the job himself. What is meant when suggesting a pre-pattern planning and design department?

A department of this type could consist of only one person, a drawing board, and a few colored pencils. In short, this department should be the place where all redesigns, possibilities of interchangeability with present flask and pattern equipment, and finally the designing of the pattern equipment complete with written pattern specifications, including the smallest of details, should be accomplished.

Casting Redesign. When speaking of redesign it is meant, of course, to give any part a thorough study in order that all possible cores be eliminated, that the blending of radical unequal metal sections be accomplished, and that proper core supports, partings, etc., are brought to the designer's attention prior to the making of the equipment.

This necessitates a selling proposition, so to speak, to the designer himself, and also a full understanding of the mechanics of the casting. Any redesign proposals that a foundryman may take to the designer should be based on three principles:

1. Will it reduce the cost of the part, or lower percentage of scrap?

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2. Will it enhance the mechanics or increase machine shop cost?

3. Will the appearance of the casting be impaired?

If these simple questions can be favorably answered by the foundryman, it seems entirely probable that the engineer will accept the modification suggested, provided, of course, that the functional qualities of the part will be maintained.

Figures 1, 2, and 3 show rather radical redesigns suggested by the foundryman to the engineer which favorably answered all three of the foregoing questions, and consequently were accepted.

The suggestion of a possible change or redesign to an engineer or a designer can have far-reaching effects. It is human nature to resent anyone suggesting even helpful revisions in our handiwork.

If we were to design and build a home, and upon its completion a neighbor were to make a critical remark about the placement of the bathroom, we would no doubt resent criticism even if well founded.

Yet, were we to build another home, is it not true that we would give the placement of the bathroom a great deal of consideration? This also is true with designers and engineers. All suggestions made may not be accepted, but each, if basically sound, will assist in the designing of future castings.

Interchangeability of Pattern and Allied Equipment. How far should we go in designing a pattern which will be interchangeable, or use a part of similar set of equipment?

It has been the author's privilege to have witnessed in operation a small foundry, newly designed, in which the mold conveyor system was comprised of three individual floor-type conveyor units. Each unit is designed to accommodate a certain area flask with consideration to the weight of the casting.

Standardization of flasks in this case is accomplished. Expensive floor space is saved, the storage of flasks in the yard is no longer necessary, not to mention the savings brought about when eliminating the need for additional flask equipment.

Flasks. In the foundry with which the author is associated the interchangeability of flask equipment has been utilized as much as possible. For example, there is one flask in which 31 individual cope and drag patterns are run. Practically all of the medium sized cope and drag flasks are used to make two or more different types of castings. These castings range from flywheels with extremely heavy sections to oil pans with extremely light sections.

Fig. 4 (Left)—Four-barrel diesel cylinder block casting, weight 990 lb., redesigned for utilization of same body cores as in 6-barrel cylinder block (Fig. 5).

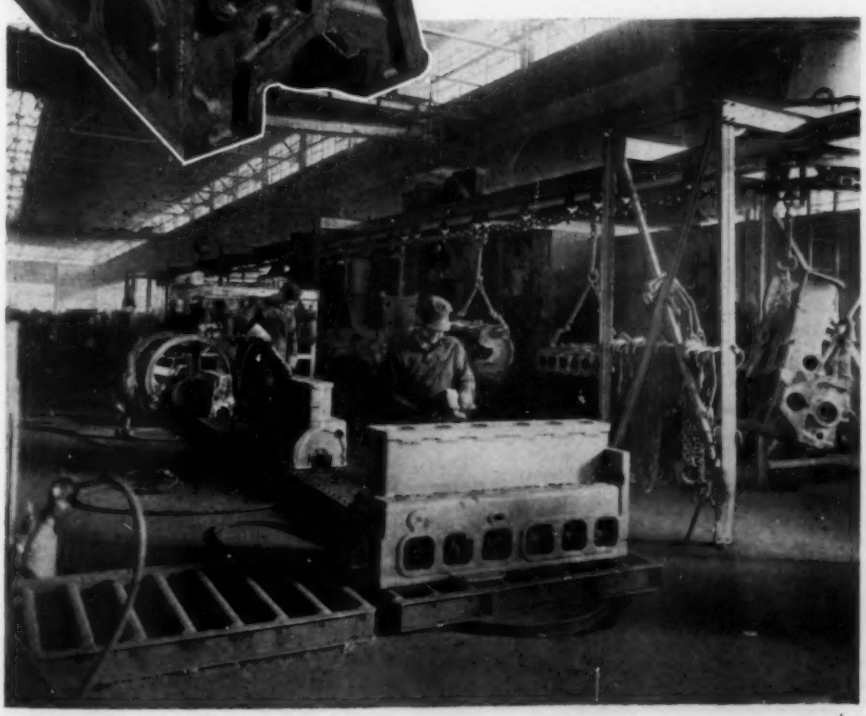


Fig. 5—(Below)—Six-barrel diesel cylinder block, weight 1260 lb., designed to utilize same body cores as 4-barrel block (Fig. 4).

Molding Machines

The interchangeability of molding machines is accomplished in the same manner. The sizes and types of molding machines have been standardized. For example, in designing the two closed flask conveyor units, only two different sized stripping machines and one size and type of rollover machine have been utilized. As a rule, rollover machines are utilized for drag molds and stripping machines for cope molds.

It has often been found advantageous to use a rollover machine for the cope mold as well as for the drag. Also, both cope and drag are run on stripping machines. This arrangement has proven very flexible and, consequently, constitutes a great saving in the rigging of patterns for machines, the ease of transferring patterns from one set of machines to another in case of breakdowns, and in maintaining this equipment with regard to interchangeability of spare parts.

Power Strip Machines

The slinger units are set up with the same principle in mind, with one exception. Only one type of molding machine is utilized. Power strip machines of various sizes are used. These machine sizes are not chosen with casting sizes or weights as the major factors; rather, each pair of cope and drag machines are purchased with interchangeability of flask sizes and pattern draw as being the main requisites.

In designing the squeezer mold conveyor unit, only one size and type of machine was installed. In regard to flask equipment used with

this unit, it might be stated that aluminum "pop-off" flasks are utilized 100 per cent. Here again interchangeability of flasks, achieved by designing the match plate pattern to fit a flask on hand, if at all possible, has resulted in a great saving, as well as the interchangeability of molding machines.

New sand ramming equipment and progress in the sand mixtures has eliminated to a large extent the necessity of barring the flasks to the 'nth degree to eliminate strains, sags, warps, drops and other looseram defects. This should allow us the privilege of standardizing to some extent in regard to flask sizes.

Patterns (not including core boxes, etc.). It has been the author's experience that interchangeability of cope and drag, match plate, or loose patterns, one with another, should be limited to some extent. With regard to small match plates, oftentimes it is costly to attempt to acquire two different castings from one pattern plate, with possibly changing a part number and a core print. The pattern must be taken to the pattern shop, the necessary changes made, and then returned to the foundry for production.

Cost Should Be Guide

If a monthly production is required on each casting, this would constitute approximately two changes per month, and possibly would soon cost as much or more than an individual pattern for each casting would have cost in the beginning. However, the production required from each and the cost of an individual set of patterns should be the guide in making a decision as to the advisability of interchangeable match plate patterns.

Cope and Drag Equipment. The utilization of interchangeable cope and drag equipment presents a different situation. Instances of similar copes or drags are numerous in this foundry, e.g., one cope pattern servicing six drag patterns in producing six individual flywheel castings, and in another instance, one flat-back cope plate with gating servicing three drag patterns in the production of clutch plates.

Truly, the greatest saving to be found in this foundry through pattern interchangeability is in the utilization of the same body cores in the production of six- and four-barrel cylinder blocks. This was accomplished only through the cooperation of the engineering department in consenting to incorporate major changes in the design to facilitate using one set of core boxes for both castings. These castings are shown in Figs. 4 and 5.

In speaking of interchangeability of cores, which is practiced whenever at all possible, it might also be of interest to describe and illustrate some of the universal core blowing plates and arrangements. The author will not elaborate upon the technique of core blowing, the technicalities involved and the advantages and disadvantages.

However, the changing of core boxes on blowing machines has been simplified in this foundry. As many as 18 different core boxes have been run on one core blowing machine during a 16-hr. period. In order to accomplish this, and not waste valuable setup time, standardization of blow plates must be brought about.

In one instance a universal blow plate was developed, as illustrated in Fig. 6, which can be used to blow a certain size and type of core. The box to be blown must necessarily have one open end for sand-laden air to enter. Due to the design of this blow plate, a minimum number of blow vents are required in the box itself. Approximately 3 to 5 min. are required to change from one box to another.

Figure 7 shows a few of the type of boxes that can be blown with the blow plate and vent plates shown in the foreground. Figure 8 shows the disassembled blow plate. In Figs. 9 and 10 is illustrated another labor saving blowing arrangement. Both cores illustrated are used for the same casting, and both are blown at the same time. Figure 9 shows these cores directly after blowing, and being removed from the blowing machine. Figure 10 shows the cores after they have been machine drawn, ready for baking.

It is sometimes found that the interchangeable patterns and core boxes present a problem. Due to great demands by army and navy departments, it has been necessary to job a large percentage of the castings to other foundries. Here is where the problem comes in.

It is a difficult matter to find many patterns that do not use interchangeable cores, flasks, or patterns which are not themselves interchangeable, so it often becomes necessary to locate a vendor with sufficient open capacity to absorb all of the jobs that are made with this

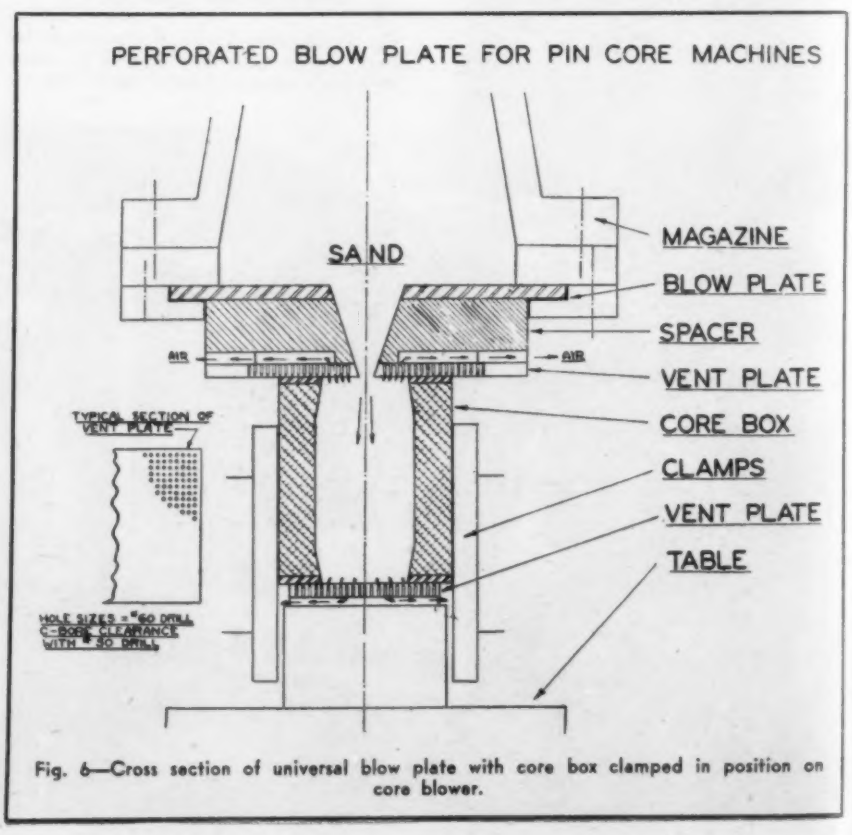


Fig. 6—Cross section of universal blow plate with core box clamped in position on core blower.

Fig. 7—(Left)—Various types and sizes of cores produced with type of blow plate shown in Fig. 6. Note lack of blow vents.

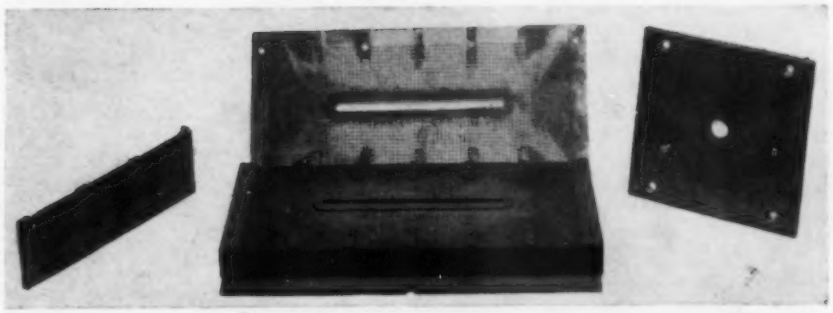


Fig. 8—(Below)—Universal blow plate (Fig. 6) disassembled.

interchangeable equipment. If the vendor can absorb all of these jobs, he of course realizes the same labor and space savings that this foundry experienced with the interchangeable equipment.

Even though the system may be "backfiring" now, the author still believes that the thousands of dollars saved through the use of interchangeable pattern and flask equipment more than offsets the problems arising from it today.

Design of Pattern and Allied Equipment. It has been stated time and again that no definite set of rules can be laid down to follow when designing pattern equipment. It is the author's opinion that this is not true. It is not the practice in this foundry to attempt the standardization of pattern equipment design, because each casting has its own special peculiarities. However, an attempt is made to follow a certain routine, or, rather, scrutinize each part with equal severity, in order to attain as nearly ideal core-making, molding, and cleaning conditions as possible.

Following a small part through its routine will serve to check the method. The part chosen is a water pump bracket, which weighs 25 lb. and has a production requirement of approximately 5,000 pieces per year. The reason for choosing a small part with modest production requirements is to impress upon the reader the equal importance in the design of either a small or a large casting. The routine steps taken to complete this pattern are given in the following paragraphs.

1. Establish parting line on blueprint, with most consideration being given to gating. Determine which is cope or drag side. (Use oil-base colored pencil.)
2. Sketch in core prints (check for possibility of redesign to eliminate same) and sketch in loose pieces, if they are found to be necessary, giving full consideration to the making and setting of cores. Sketch crush strips and close-over clear-

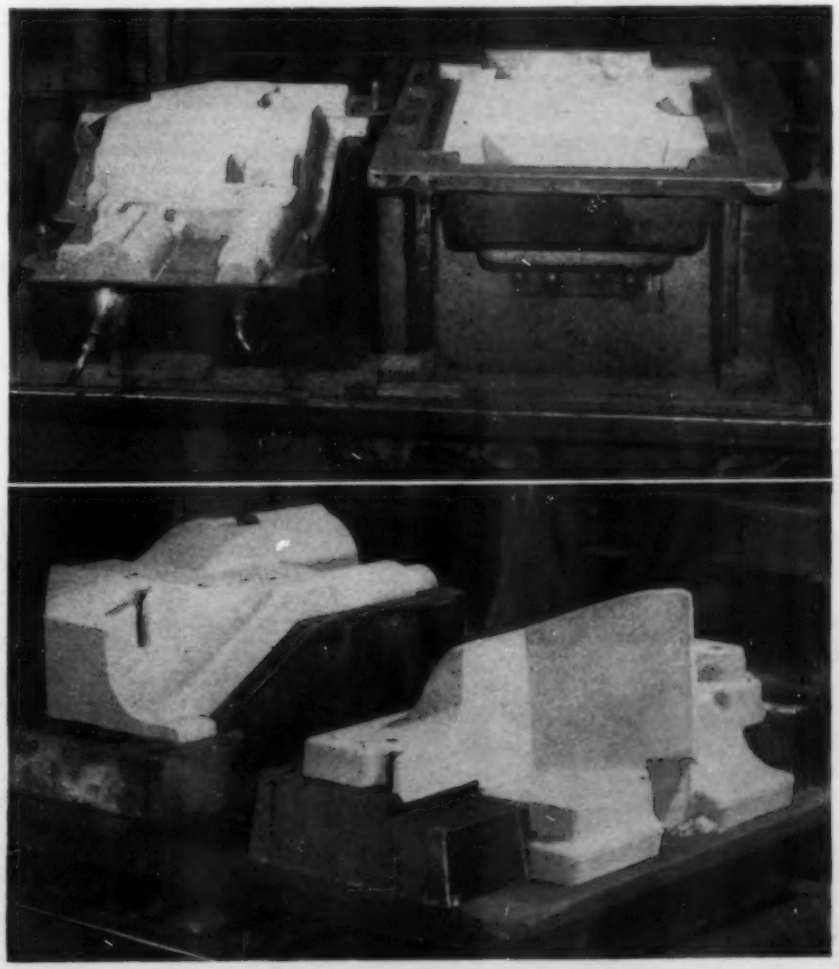


Fig. 9 (Top)—Both cores are for the same casting and are blown at the same time. Note boxes tied together with rail at bottom. Fig. 10 (Bottom)—Cores (Fig. 9) after drawing and ready for baking.

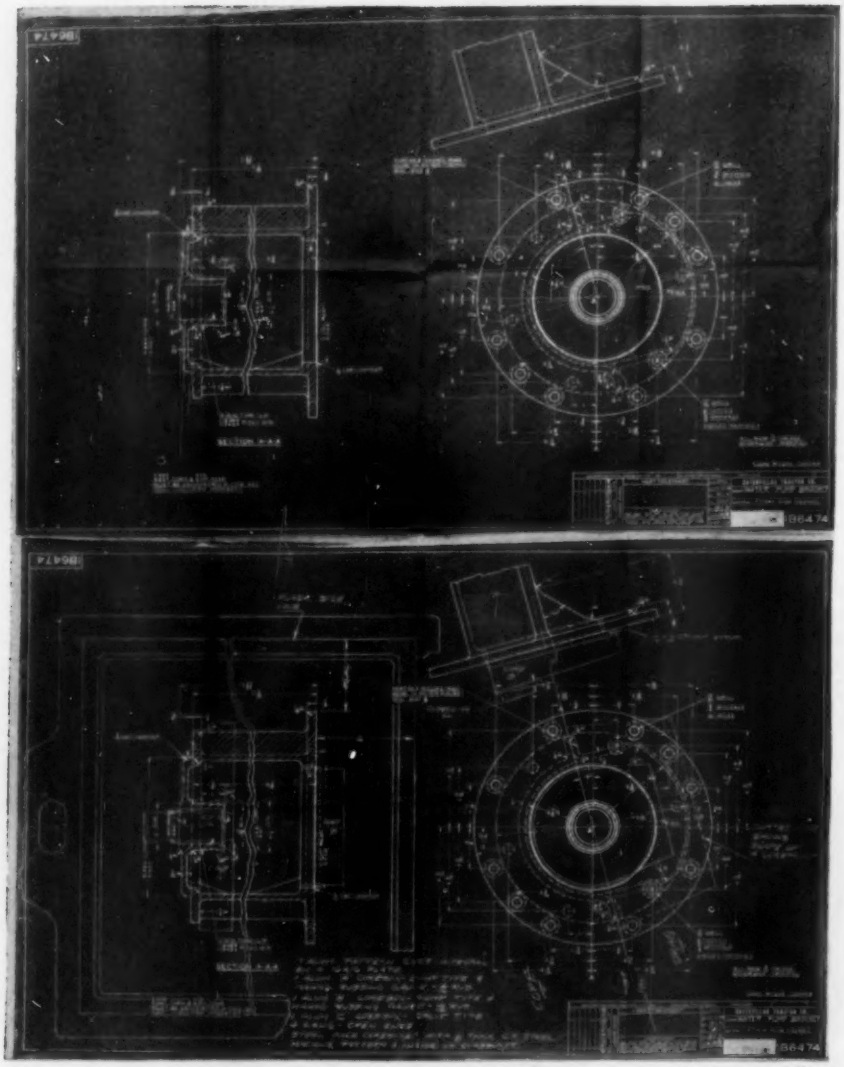


Fig. 11—Upper blueprint is complete as received from engineering department. Lower blueprint is complete after pattern designing has been accomplished. See Figs. 12, 13, 14 and 15 for various stages to finished casting.

Fig. 12—Soft pine master parrern mounted in match board to produce aluminum match plate.

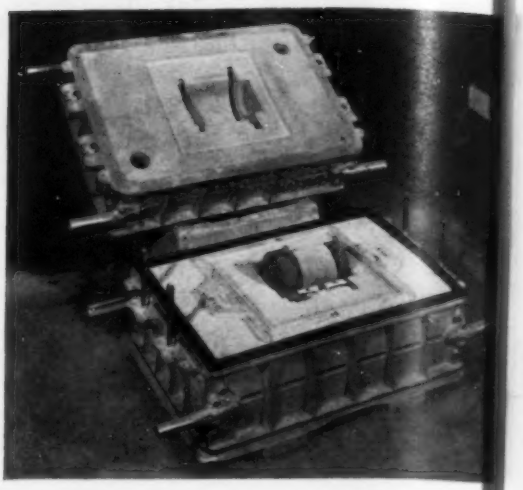


Fig. 13—Partially completed mold of aluminum match plate (Fig. 12).

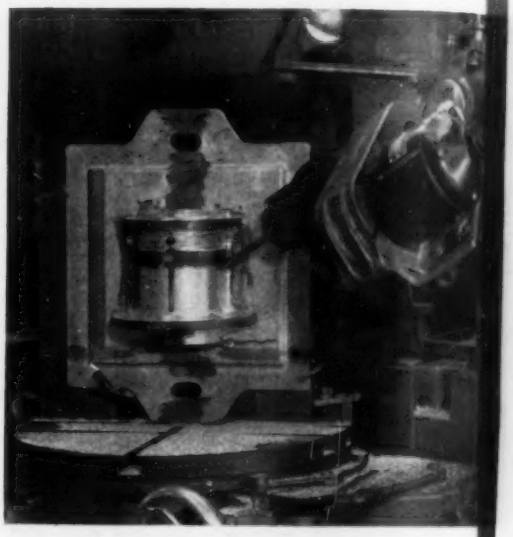
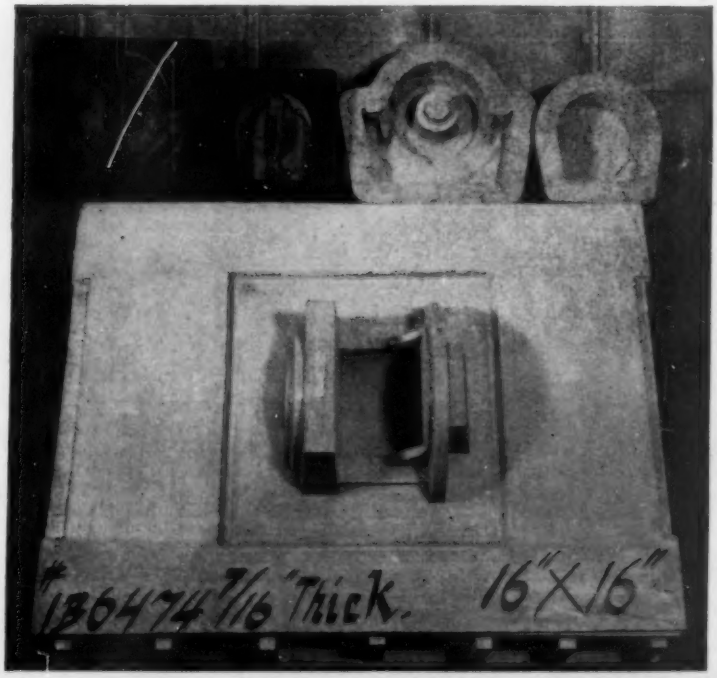
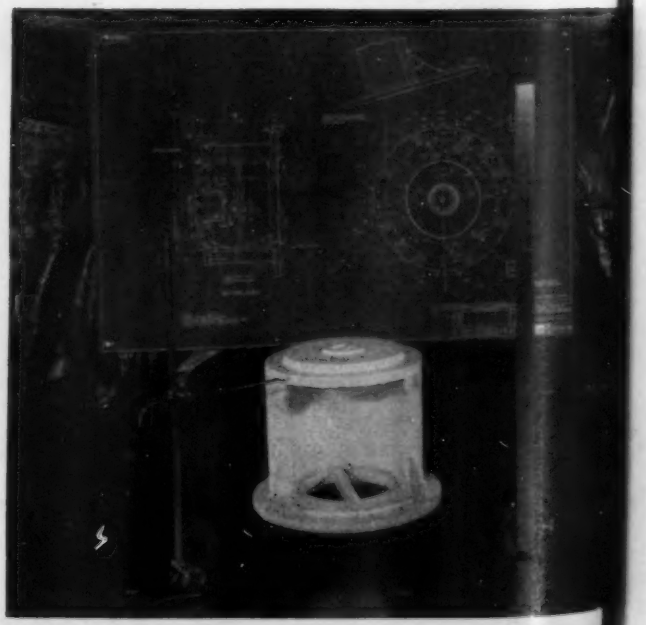


Fig. 14—Sand-cast aluminum match plate with pattern being machined for accuracy.

Fig. 15—First sample casting obtained from completed match plate equipment (Figs. 11, 12, 13 and 14). Note layout lines.





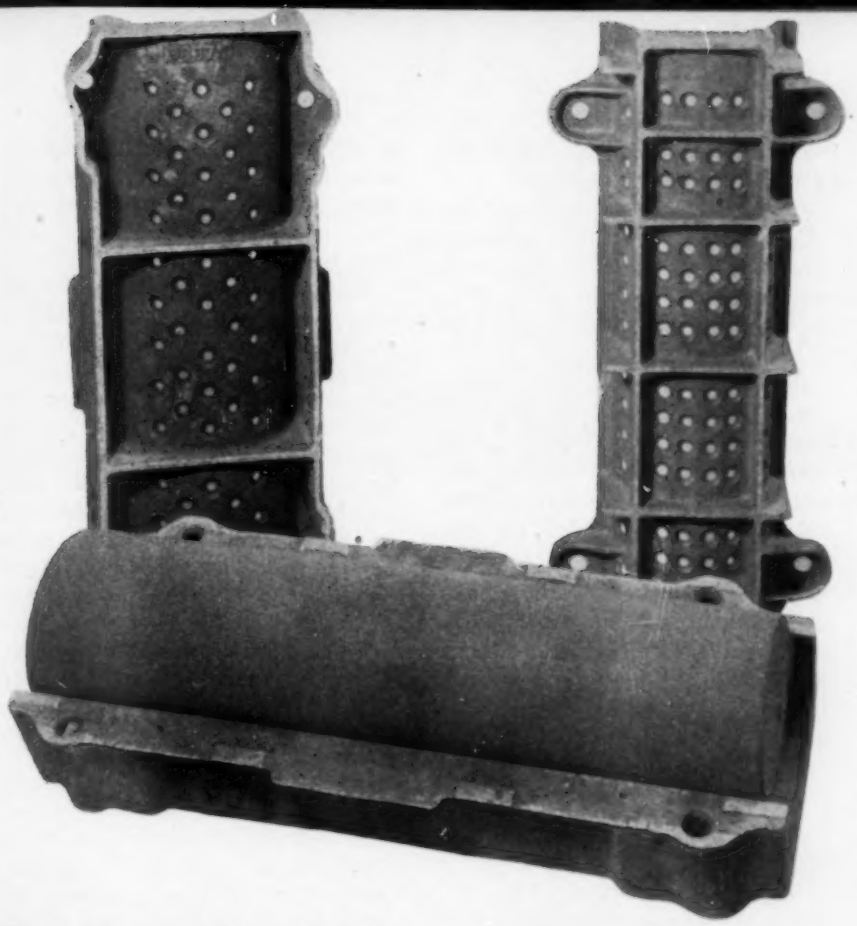


Fig. 16—New (left) and old (right) designs of cylinder liner core dryer.

in both warping and breakage. Approximately every 4 months the entire group of dryers were taken to the pattern shop for straightening, and continual replacement of broken dryers was necessary. Also, this dryer often tipped over after being placed on the core rack.

These disadvantages made necessary the designing of a new dryer and, finally, the design shown on the left in Fig. 16 (with the core at rest in front) was adopted. This is a box-type construction, and is considered to be a non-rocking, non-warping, non-breaking dryer.

Three hundred of these dryers have been used in continuous production for 4 years. One dryer has been broken, and they have yet to be reworked in any way. This de-

Fig. 17—(Below)—Specially designed aluminum core plate. Note construction to insure better baking of plate surface of core.

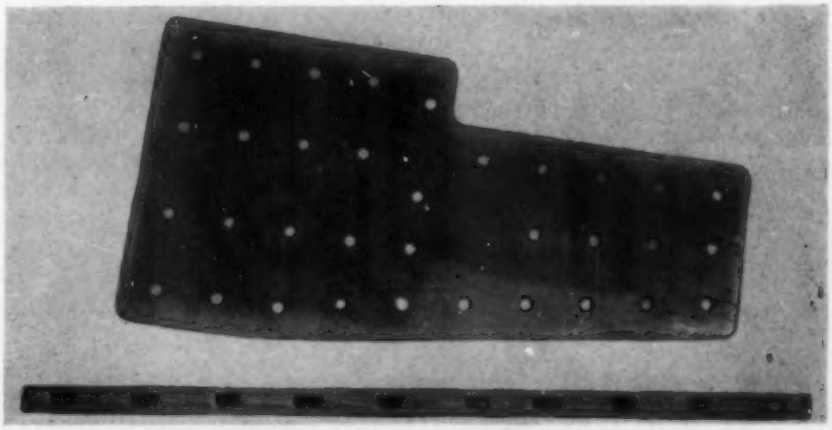


Fig. 18—(Right)—Complete assembly of body cores necessary to cast six-barrel cylinder block shown in Fig. 5. Cores are not rubbed on the joint. Over-all assembly allowed ± 1/16-in.

ances, and letter each core in the sequence in which it will be placed.

3. Sketch outline of plate and flask around pattern, allowing ample room for proposed gates and risers.

4. Provide written pattern specifications in detail, specifying pattern material and any allied equipment, such as core rubbing or grinding fixtures, dryers or special core plates.

5. Check layout for any item that can be provided to eliminate the possibility of any discrepancy that may arise.

Figures 11, 12, 13, 14, and 15 illustrate, in part, the growth of a casting from the blueprint to the cleaned casting.

Hints in Designing Core Dryers and Core Plates. A core is seldom more accurate than the dryer or plate on which it is supported until baked. As a rule, foundrymen are apt to slight the design and maintenance of core dryers and plates. Figure 16 shows two designs of core dryers. Both dryers are used to bake the same core.

The old design, with all ribs and the four dowel pin lugs protruding from the dryer, is shown on the right. This design was very costly

sign has been extended to all types of core dryers wherever possible, with the same results.

In Fig. 17 is shown a specially designed aluminum core plate which is used to support the diesel cylinder block cores during baking. Prior to the use of this core plate, numerous designs and materials were used, all with the same results. The cores would not bake out on the plate surface, or the plates themselves would warp, which made it necessary to grind the cores in a fixture.

After designing the type of core plate shown (Fig. 17), the cores were found to be flat and it was possible to eliminate the grinding operation, which resulted in a direct saving in labor, plus the fact that the cores which are not ground are more accurate than those which are ground.

Figure 18 shows a complete six-cylinder diesel body core assembly ready for the mold. Twelve cores are bolted together and are held to an over-all length dimension of plus or minus 1/16-in.

Prior to using this present plate, a cast iron plate was used. Two men were required to lift the cast iron plate upon the box, whereas with the present aluminum plate only one man is needed for this operation.

The design of the aluminum plate is such that there are two 7/16-in. thick parallel faces, vented as shown in Fig. 17, tied together with ribs and bosses of equal metal thicknesses. The plate was cast, annealed at 700° F., and then machined on both surfaces. The top and bottom plates are 1 in. apart, allowing the free circulation of hot gases and even heating and cooling.

For foundrymen to close their eyes to the competition offered by the welding and powder metallurgy processes would be dangerous indeed. Methods of producing castings at lower costs and with closer tolerances must be developed. It cannot be expected that foundry raw materials will cost less. Rather, because of shortages, the foundryman must be prepared for higher material costs. Only through the development of methods to increase production, labor saving foundry equipment, and progress in pattern design can the foundryman hope to compete.

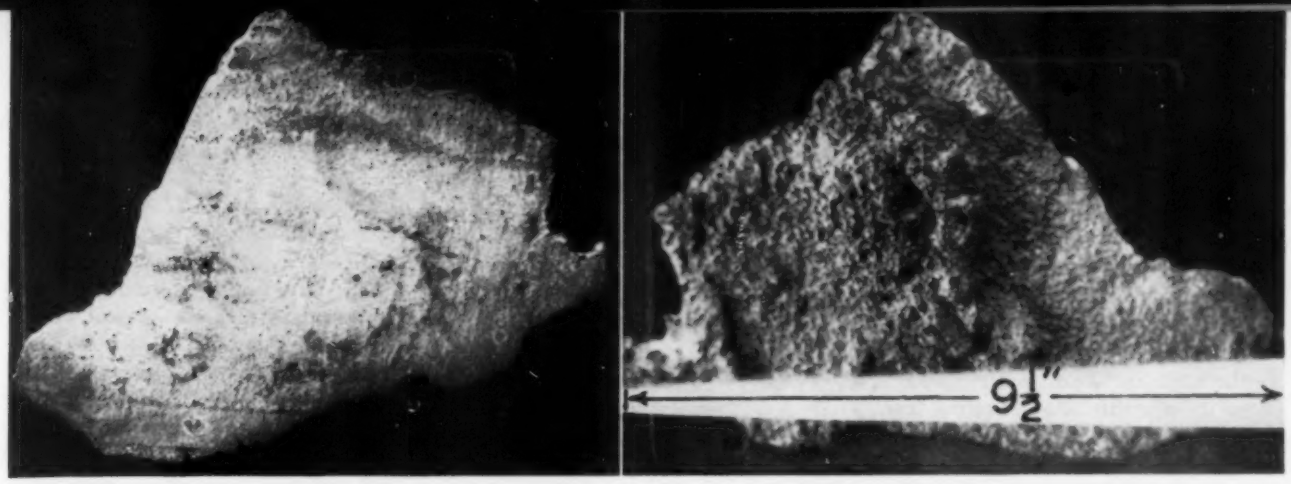


Fig. 1 (Left)—Surface of specimen of adhering sand in contact with steel. Fig. 2 (Right)—Opposite surface of specimen of adhering sand shown in Fig. 1. (Specimen size reduced in reproduction.)

1944-45 SINTERING TEST

• Report of the Committee on Sintering Test, Foundry Sand Research Project of A.F.A.

THE condition of "burnt on" or adhering sand can be very contrary, and because it is so contrary, can be quite puzzling. One type of adhering sand, spotty "burn on," seems to be especially puzzling. When this type of adhering sand is encountered, the cause usually can be traced to soft ramming. This spotty "burn on," due to soft ramming, will vary from casting to casting, molder to molder and from day to day on the same castings. In fact, one part of a casting will show bad adhering sand, while an adjacent area will peel perfectly.

When this type of adhering sand does occur, the foundry seems to look always for some mysterious change that has occurred in the sand. In reality, what has happened is that the molder did not ram that mold, or that particular part of the mold, hard enough.

Regardless of how refractory the sand may be, if it is not compacted enough, the voids present in the sand as rammed are so large as to allow mechanical penetration of the metal into the sand mass, with bad "burn on" resulting. Simply because the mold surface was washed does not mean that penetration cannot occur, as no wash is perfect. It can and will spall or crack in spots, opening up potential entries for the metal into the open sand back of the wash.

Just such an example of adhering sand was submitted to the Sintering Test Committee during the past year as a very mysterious type of "burn on." Figures 1 and 2 show a large area of this adhering sand that could be pried off a large steel casting with difficulty. This mass did come off, but other spots could not be removed, and there were so many of these spots that the casting had to be scrapped.

Figure 1 shows the surface in contact with the steel. It is quite smooth and shows no unusual fusion. However, please note that this surface, which had been washed with silica flour wash and should have been impervious, shows numerous imperfections, mostly cracks. These imperfections show black in Fig. 1.

The reason that they show black is that they are filled with steel and a little air was present to oxidize the surface. These small cracks are, in this case, the passages through which the steel penetrated the dense wash and permeated the more open sand back of the face of the mold.

Fig. 3 (Left)—Cross section through area showing ¼-in. penetration (Fig. 2). 25X, vertical illumination. Fig. 4 (Right)—Cross section through area showing ⅜-in. penetration (Fig. 2.). 25X, vertical illumination.

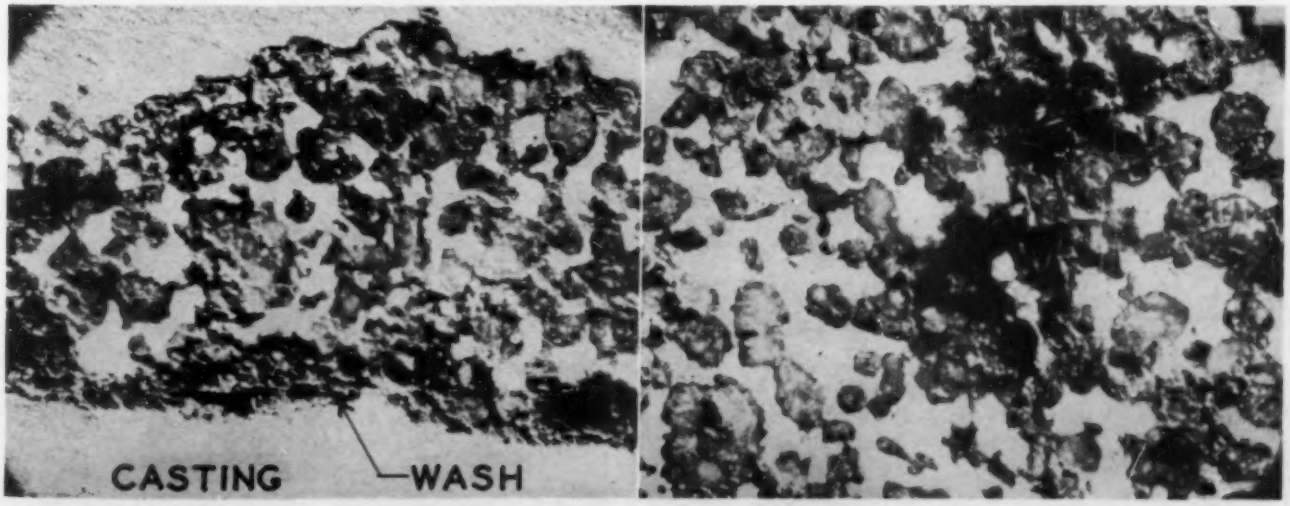


Figure 2 shows the other side of this sand mass. Only that part of the sand which was permeated by the steel has remained in one piece. The sand into which the steel did not penetrate disintegrated on shakeout. The thickness of this mass of sand and steel increased from ¼-in. at the edge to ⅞-in. in the center. Even though this photograph is less than natural size, it can be seen that the sand in the center of the specimen is quite open. It is in this area that the steel penetrated the farthest.

Mechanical Penetration

Figure 3 shows a cross section of this mass of sand and steel at the edge of the penetrated area, where the steel penetrated the sand to a depth of ¼-in. The magnification is 25 diameters. The metal penetration (white areas) and unchanged sand grains (gray) are typical of pure mechanical penetration. Note that the voids, now permeated by the steel, are larger than the sand grains, and that the wash is not continuous, even though to the unaided eye this surface seems to be uniformly covered.

Figure 4 explains why the center of this specimen showed ⅞-in. metal penetration. This area must have been rammed very soft, for otherwise how can the extremely large spaces between the sand grains be explained? The particular area in this micrograph was taken as far back from the sand-metal surface as possible, ⅞-in. from this surface.

The metal this far back is starting to freeze off and, as can be seen, there are two large voids (the black areas) that were not filled by the metal. Nevertheless, there is still enough steel present to bond the sand grains together, making a good grinding wheel on the surface of the casting.

Ramming the Mold

The moral of all this is ram. Ram as hard as possible, consistent with other properties of the sand *in the mold*. Of course it is possible to ram too hard, but soft ramming will cause "burn on" as well as swells and strains. No sand will peel if it is not compacted sufficiently.

Do not depend on a wash to do everything. It must be backed by the proper sand. If spotty "burn on" is encountered, do not worry about some mysterious change that has occurred in the sand, but get out the hardness tester and check the hardness of the mold; not at the parting or some other nice flat surface, but at the gate, pockets and corners.

These areas are not only the ones that are the hardest to ram and usually are rammed softer than the rest of the mold, but are the ones that are partially surrounded by metal and are heated to a higher temperature. This combination, large voids due to soft ramming, plus being heated close to the metal temperature, makes these areas doubly susceptible to penetration by the metal with bad "burn on" resulting.

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REFRACTORIES *for Electric Melting in the* FERROUS FOUNDRY

By E. K. Pryor and L. R. Burke, The Charles Taylor Sons Co., Cincinnati

REFRACTORIES in electric melting operations probably receive more severe abuse than in any other service. Replacement is always a matter of weeks. Unfortunately, it appears most likely that refractories will always have a relatively short life in such service. This limitation is imposed by the very nature of the operation. The extreme temperatures involved not only mean greater slag and flux activity but also tax the heat-resisting qualities of refractories to the utmost.

Electric furnace design features also place a handicap on refractories. For efficient operation the furnace volume, above that occupied by the charge, must be kept to a minimum. The result is a relatively small area for dissipation of heat. Only small design changes are permissible without seriously disturbing the efficiency of the melting unit. Such changes are being made when possible and as the value of the change is recognized.

Refractory Improvements

This does not mean that we have reached the service limit for refractories in electric melting operations. Manufacturers of refractories are constantly striving to improve their product. Improvements have not been spectacular but the progress has been steady. If a service comparison of a brick made 10 years ago were made against the same brand as made today, the results would be remarkably favorable to the latter.

Manufacturers are definitely limited by the known available raw materials. Most progress must be made through improvement of the physical properties. The approach in such effort is ably described by Birch*.

The operator of electric melting units can play a part in improving the service he obtains from refractories. In some instances, by observing a few precautions in operations, a great increase in refractory life is possible.

Refractory Failure

In electric melting refractories fail, principally, for the following reasons:

1. Chemical attack by fluxes, dusts and slags
2. Erosion by slags, molten metal and charge.
3. Spalling; thermal, structural and mechanical.
4. Insufficient refractoriness.
5. Mechanical abuse.
6. Insufficient hot strength.

Almost always each of the foregoing factors will contribute to the ultimate failure of every furnace lining. The degree will vary greatly with the type of operation and the kind of refractory used.

Chemical attack or corrosion will vary in degree depending upon the following factors:

a. Compositions of the refractory and the fluxing or slagging agents.

b. Fluidity of the reaction products.

c. Temperature of furnace.

d. Temperature difference between hot and cold face of the refractory.

Refractories usually are placed in three categories; acid, basic, and neutral.

For electric melting operations, the following refractories are acid:

Fire Clay	Sillimanite
High Alumina	Zircon
Kaolin	Silica

There are those who would imply neutral properties for high alumina refractories containing over 60 per cent alumina, and for sillimanite type refractories. It is true that they will resist basic slags and fluxes better than materials of lower alumina content, but essentially any of these products will react acid in the presence of strong bases and similarly will react basic in the presence of strong acids.

Properties of Silica

Silica will withstand the action of iron oxides alone better than the alumino-silica refractories, fire clay, high alumina, kaolin and sillimanite. The fusion points of these materials are lowered markedly by small amounts of iron oxides, whereas the fusion point of silica is not materially lowered until the iron oxide concentration approaches 40 per cent.

Similarly, silica will withstand the attack of lime without much damage until the lime concentration reaches 27 per cent. Silica will probably withstand the attack of fluxes and dust in the furnace atmosphere as well as any of the foregoing but, where temperatures exceed its soften-

*R. E. Birch, "Phase Equilibrium Data in the Manufacture of Refractories," *Journal*, American Ceramic Society, vol. 24, no. 9, Sept., 1941.

• Electric melting imposes severe refractory service conditions. Progress has been steady in refractory manufacture, particularly in physical property improvements. A few simple precautions observed in electric furnace operation will prolong refractory life in this increasingly important type of melting.

ing point, the more refractory products, such as high alumina and sillimanite, should be investigated.

The following refractories are basic:

Magnesite
Fused Magnesia Forsterite

Improved Magnesite Refractories

Magnesite is becoming more widely used, almost daily, in the side walls of basic direct-arc furnaces. It resists the attack of basic slags very well. It is available in improved and modified forms that are rapidly displacing the old standard magnesite brick. Slags containing excess silica will attack it quite rapidly at temperatures above 2800° F. Likewise, drip from silica roofs, running down the side walls, channels into the magnesite with alarming rapidity at times.

This is overcome by some operators through the use of a "buffer" course of chrome brick between the two. Chrome will not react appreciably with either material. Magnesite's poor spalling resistance and low hot-load capacity have limited its application somewhat. These shortcomings have been minimized in recent years, but there is still room for improvement.

Forsterite brick are relatively new and have yet to find appreciable application in electric furnace operations. Basic slags apparently attack it at a somewhat greater rate than in the case of magnesite.

Fused magnesia is used principally as a lining material for high frequency induction furnaces, most frequently with an addition of approximately 30 per cent of fused alumina. Fused magnesia has found no other applications in ferrous melting. It is not to be confused with sintered magnesite, so widely used as a basic bottom material in three-phase arc furnaces.

Neutral Refractories

Chrome and fused alumina are classed as neutral refractories. Chrome comes nearest to being neutral, chemically, of all the more common refractory materials. It has very excellent resistance to both acid and basic slags and fluxes.

It is frequently used as a "buffer" course between acid and basic refractories. Perhaps the largest percentage of chrome today is used in brick combined with magnesite to make the so-called chrome-magnesite refractories that are being more widely used day by day.

The application of the higher-chrome-content refractories has been limited in electric melting by the fact that chromium metal is fairly readily reduced from the refractory during the periods in which reducing conditions prevail in such operations. Many times this feature is given undue stress, but there are conditions where it must be considered.

Fused alumina also is rated as a neutral refractory, but it does not have the resistance to basic and acid slags or conditions to the degree that is often implied. The use of straight fused alumina products cannot be generally justified outside of laboratory operations.

As pointed out, fused alumina has found its principal application, when mixed with fused magnesia at a ratio of about 30:70, as a lining material for high frequency induction melting units. In this instance it has been very satisfactory, but as tile and brick for linings in direct- and indirect-arc units, alumina products have not shown advantages commensurate with the high cost.

Composition Equilibrium

Essentially, within practical limits, a refractory with a composition most nearly in equilibrium with the slags and fluxes present in the melting operation should be chosen. Thus in a basic operation the use of magnesite products will generally give the most satisfactory results, as will silica in acid melting operations.

Other factors to be discussed limit the degree to which this may be carried out. A compromise is always necessary in the selection of a refractory for a high temperature melting operation.

The fluidity of the slag or reaction product has a great influence on the degree of destruction of refractories by chemical attack. If the slag is quite fluid and flows over the face of the refractory with relative rapidity, the corrosion rate also is rapid. The products of the corrosion are carried away, leaving a new surface of refractory open for attack.

As the viscosity of the slag or reaction product increases, the rate of the attack is reduced proportionately. A point may be reached where, actually, the reaction product is of such viscosity and refractory nature that it will effectively serve as a protective layer against further attack. This condition is seldom if ever reached in electric melting operations.

Operating Temperatures

The temperature at which melting operations are carried out will likewise affect the chemical attack. In some instances, chemical activity increases most markedly with temperature rises. This, coupled with increased fluidity of reaction products, means greatly accelerated erosion rates.

Temperature limits can be, and often are, very critical. Not infrequently, by carrying the temperature even 20 or 30 degrees lower, a marked improvement in refractory service is obtained. It is certain that silica roofs and side walls are not going to stand up at temperatures of 3100° F. as well as they will at 3050° F.

In the case of basic brick, temperatures that will actually fuse the brick are not likely to be reached. Temperatures can be and are reached that will soften the bond betwen the refractory grains of the brick. Thus, the brick loses most of its strength.

Molten metal and slag, if active, may wash the bonding material from around the refractory grains, which are in turn carried away. Because of the lack of hot strength, basic brick have not yet been successful in direct-arc furnace roof construction.

The temperature difference between the hot face and the cold face of the refractory is important. It is because of this difference that brick can be used at temperatures equal to their fusion point.

Temperature and Load

That portion of the brick away from the heat source carries the structural load—if the brick were at the hot face temperature throughout, failure would be rapid. Insulation of direct-arc furnaces will lessen the life of the refractories, as the outer surface of the brick tends to approach the extreme temperatures of the hot face.

Likewise, the steeper the temperature gradient, that is, the greater the difference between the hot- and cold-face temperatures, the less the

penetration of fluxes and slags into the brick proper. This latter, of course, means a slowing down of chemical attack and, too, a lesser depth of vitrification of the refractory. This is important in the consideration of spalling.

The porosity of the refractory also affects the rate of chemical attack. If the brick is open in structure, the metallic vapors and fluxes can penetrate into the brick structure more readily and thus attack a greater portion of the brick at one time. As has been mentioned, the composition of the refractory relative to that of the slagging or fluxing agents present will markedly affect the reaction rates.

As previously stated, FeO will not attack silica refractories at an appreciable rate alone until a concentration of 40 per cent FeO is reached, but the addition of a small amount of alumina will cause the reaction to proceed rapidly and with but a small percentage of FeO present. Similarly, an FeO-CaO slag will not attack magnesite brick appreciably, but if SiO_2 is substituted for the CaO the attack will be rapid.

Refractory Erosion

Erosion of refractories is the wearing away of the refractory by slags, molten metal and flame or flux burdened hot air currents over their surfaces at varying rates. Invariably this is a combination of mechanical and chemical wear. Generally speaking, the more rapid the rate of flow, the greater the amount of erosion for a given period of time.

In furnaces such as the high frequency induction and indirect-arc rocking-electric, erosion is inherent to their operation; in the direct-arc unit it is incidental, varying with bath activity. In no case can it be completely avoided.

Spalling. Spalling is the separation of a brick or refractory mass into two or more pieces, resulting from stresses incurred under service conditions. Spalling is of three types; thermal, structural, and mechanical.

Thermal spalling is the result of rapid and unequal expansion or contraction of a refractory mass due to non-uniform heating or cooling of the mass. This can never be completely eliminated in production operations. With care in the selection of the refractories, and in the operation, it can be minimized.

Heating and Cooling Rates

Most important is the selection of heating and cooling rates best suited for the refractories involved, and making certain that the furnace is protected from air currents circulating through it as the unit is cooled.

Thermal spalling may be recognized by the typical "cobblestone" appearance of the surface of the masonry. Silica, magnesite, and chrome refractories are most subject to thermal spalling; sillimanite types and super-duty fireclay refractories the least. Generally speaking, a refractory of open "elastic" structure will be the most spall resistant.

The more dense and finer-grained brick are most likely to be susceptible to spalling. Other things being equal, the brick having the greater expansion coefficient will spall the most. Silica is unique in that it undergoes two abrupt volume changes in being heated to a temperature of 1100° F. Above that temperature it is practically volume stable and can undergo marked temperature changes without damage.

Extreme caution should be observed when heating or cooling it between 300 and 500° F., and again from 900 to 1125° F., as all thermal spalling of silica will occur within these temperature ranges.

Structural Changes

Structural spalling results from a change in the physical structure or mineral composition of a refractory due to the action of heat or the combined action of heat, slags and fluxes. Often this change results in a material more subject to thermal spalling or shock than the original structure.

Thus, when a brick end has become vitrified or glass-like, the resulting brittle mass can stand very little temperature variation without undue stresses developing within the mass, which stresses are relieved only through cracks forming in the brick.

Similarly, when heat has caused the bond between the refractory grains to soften, the entire mass shrinks into a more dense form of less porosity and volume. In this, and the first condition, the altered part of the brick tends to pull away from the original structure at the transition zone between the two portions. Relatively slight thermal or mechanical shock that otherwise would have no effect may result in a separation near the transition zone.

New mineral forms, resulting from the action of heat and from chemical attack, may be of greater or less specific volume, resulting in a condition similar to shrinkage. The expansion characteristic also may be altered in the new mineral form. Any of these will mean a greater tendency toward spalling. Such spalling is called "structural," although thermal shock may play an important part in ultimate failure.

Alumino-silica refractories such as super-duty, fire clay, and sillimanite or mullite types, along with magnesite and chrome, are more likely to suffer structural changes resulting in structural spalling than is silica.

Masonry Structure

Mechanical spalling is the result of concentrated stresses developed in the masonry structure, generally due to faulty masonry. When these stresses are sufficiently great the brick fractures to relieve these strains. This type of spalling is most generally found in arches that have been laid up too tightly.

When they are heated the expansion of the brick causes the crown to push upward and the stresses are concentrated in the lower edge of the brick, on the under side of the arch, rather than being distributed over the entire brick surface. "Pinching" results, the lower ends of some of the brick breaking away until the stress distribution is more uniform.

Insufficient Refractoriness. This is not unusual in electric melting operations. Fireclay refractories almost invariably fail in electric melting operations because they begin to soften long before actual melting begins. Most high quality fireclay refractories have a fusion point at temperatures of about 3100° F., but they soften well below this temperature and it is doubtful if they are of

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Refractories Committee of A.F.A.

much use in electric furnaces at temperatures of about 2950° F.

Silica has a fusion point just below 3100° F., but fortunately it does not soften until just a few degrees below its fusion point. Its usefulness in electric melting is markedly greater than that of fireclay products in spite of the fact that the latter have a considerably higher fusion point in some instances. Sillimanite has a fusion point approximately 3335° F. and, like silica, does not soften until within a few degrees of the fusion temperature.

Fusion Temperatures

Both chrome and magnesite refractories have fusion temperatures above those used today in electric furnaces. Unfortunately, the bond material in these brick will soften at much lower temperatures, so the brick fail if stressed or loaded to any appreciable degree. Zircon, which is finding application in electric melting, also has an extremely high fusion point.

Much has yet to be learned of the limitations of zircon in electric furnaces. It does seem to have merit when used in indirect-arc rocking electric furnaces melting ferrous alloys. High alumina fireclay brick have sufficient refractoriness but are subject to excessive shrinkage when exposed to high temperature for long periods, such as in electric furnaces. They too soften at temperatures appreciably below their ultimate fusion temperatures.

Mechanical Abuse. Mechanical abuse is something about which the refractories manufacturer can do nothing. It is strictly a plant operator's problem; a difficult one today with the class of labor now available. Most mechanical abuse takes the form of direct destruction of refractories by lack of care in charging and rabbling.

Such abuse generally contributes more than is realized to the ultimate failure of refractories, particularly those about the doors and at the metal line. Guarding against such abuse deserves more time and consideration than is usually given it.

Insufficient hot strength is found principally in fireclay refractories and in chrome and magnesite products. In the former, the entire mass of the brick softens and will not support a load. A roof of fireclay will sag while it is otherwise still serviceable, particularly if the operation is a cold melting one.

This sagging is due to the loss of hot strength as the brick progressively softens at temperatures well below its ultimate fusion point. If it were not for this, fireclay refractories would undoubtedly be used for roof construction in many more operations than it is at present. With chrome and magnesite refractories, the basic refractory grains do not soften but the matrix or bond surrounding these grains does.

As liquid develops in this matrix it acts as a lubricant to the grains so that they may slide over one another; when sufficient liquid develops the brick will no longer stand any loading. Grain shape and characteristic determine the amount of liquid necessary before failure occurs. If the grains are rough, more liquid is required than when they are rounded and smooth. If they had interlocked surfaces they probably would be able to stand up until chemical attack alters the surface.

Unfortunately, grain intergrowth does not occur in magnesite refractories, and increasing the hot strength of these refractories is a difficult problem. Progress is being made, but it appears that it will be some time before a basic roof for electric furnaces will be possible if made in the conventional sprung-dome form.

Silica, sillimanite types and superduty fireclay refractories have the greatest hot strength under load; magnesite and chrome the least.

Direct-Arc Furnace

Roof Construction. Since by far the largest percentage of electrically melted ferrous metal is produced in this type of unit, it is logical that refractories for the direct-arc furnace should be considered first.

The principal causes of failure of the refractories in a direct-arc furnace roof are chemical attack from the furnace atmosphere, spalling, and temperature. These causes are not necessarily listed in the order of importance, as the more serious of these various factors of destruction will vary from plant to plant. In all cases, however, each will contribute significantly to the ultimate failure of the refractory.

It might be well to stress that, while the main body of the roof construction is subject to attack as previously indicated, the conditions causing failure are more intensified at the center portion of the roof, and more specifically around the electrode openings.

The chimney effect created by these openings results in the constant washing of the refractory around the opening by the flux-laden atmosphere of the furnace. The chemical attack on the refractory at this point of the roof construction is thus greatly accelerated. In addition, thermal spalling is more serious in this part of the construction.

Realizing this fact, it is not difficult to comprehend why roofs are so often removed from service due to failure of the delta-section while there is still a serviceable thickness of refractory remaining in the balance of the roof. Investigation of a super-refractory, such as sillimanite, to reinforce this portion of the construction might be advantageous.

Silica in Roof Construction

Silica is by far the most commonly used refractory material for roof construction in this type of melting unit. The relatively high hot strength of silica makes it particularly adapted to this application.

While it is conceded that neither the fusion point nor the resistance to chemical attack by the fluxes present is the ultimate for an electric furnace roof refractory, it must be agreed that silica is sufficiently resistant to these forces of destruction to make its application practical.

A serious objection to the use of silica roof construction is its characteristic irregular expansion, which makes the material susceptible to thermal spalling. This characteristic is particularly objectionable where the furnace operation is intermittent.

A satisfactory solution to this difficulty is the use of a gas burner in the furnace to keep the temperature above the critical expansion range of silica. The tendency of silica to spall might also be a factor in top-charge furnaces, but under normal operation the roof is not off the furnace long enough to cool the brick below the critical temperature.

In either of these instances, the use of an improved silica cement now available will help reduce excessive wear of silica brick or shapes due to thermal shock. While the cement will not prevent the silica

from cracking, it will be of positive aid in preventing the cracked portion of the brick from falling away to leave new surfaces exposed to further attack.

Another serious objection to silica roof construction is contamination of the slag from silica drip. Under certain operating conditions, this siliceous drip can be sufficiently serious to make a silica roof impractical. This factor is of consequence only in basic operation.

As indicated, despite the common application of silica for roof construction, it does have its shortcomings. Consequently, we find other refractory materials used in place of silica. Due to their increased thermal spalling resistance, super-duty fire brick are sometimes used successfully in place of silica, but the extent of the application is limited because of the characteristic softening of such brick under load at temperatures appreciably below their fusion point.

Alumina-diaspore, or high alumina, kaolin, and sillimanite are used to a limited extent. Despite the relatively high initial cost of these materials over fireclay and silica, their application proves economical under certain operating conditions. The good hot-load bearing and high refractory characteristics of these materials make them adaptable to the application under discussion.

Roof Refractory Properties

The excessive shrinkage of the diaspore-alumina material is objectionable, and undoubtedly is a limiting factor in its use for roof construction. All of the foregoing materials, being Al_2O_3-SiO_2 refractories, are adversely affected by the iron oxide dusting from the furnace atmosphere.

The diaspore-alumina and sillimanite refractories are also subject to structural spalling resulting from the absorption of fluxes at the hot face.

The reaction of the refractory with these fluxes, at the high operating temperatures, forms a product with a different specific volume than the original brick. When the furnace cools, this reaction product peels away from the main body of the refractory, leaving new surfaces exposed to attack. Depending upon conditions, the effect of this reaction will be to a depth of ½ to 1 in.

Despite these limiting factors, sillimanite, due to its high refractoriness, excellent hot strength and resistance to thermal spalling, is particularly adapted for electric furnace roof construction. The high cost of sillimanite is the principal consideration limiting its more general acceptance for this application.

Chrome-Magnesite Refractories

Although chemically suited and amply refractory for direct-arc furnace operation, chrome-magnesite brick have not been used in electric furnace roof construction with any success. The lack of application can be attributed to the structural weakness of the present basic brick, which will not withstand the stresses and strains of the present dome-shape construction.

In this application, structural spalling, due to iron oxide absorption at the hot face, would also be encountered. This type of brick is also susceptible to thermal spalling. These latter two factors, however, would not prove too serious if the manufacturers of basic brick are able to improve significantly the structural weakness of the present day product.

Investigations are now under way to develop basic roof brick for the basic open-hearth furnace. Developments from this work may prove adaptable in foundries following the basic practice.

Bottom. Although subject to significant slagging action, it is probably the abrasion from charging that is the most serious factor affecting the furnace bottom. The maintenance of a tight monolithic structure also is important, as development of cracks will permit penetration of molten metal, resulting in eventual disruption of the hearth.

In acid practice, the hearth will be a monolithic construction of either sand or ganister. In basic practice, the hearth will be a sintered magnesite, or more likely, a rammed magnesite. This latter, a relatively new development, seems to have become definitely established practice.

Side Walls. The side wall refractory must withstand chemical attack, as well as the erosive action of molten metal. The metal line of the side wall is particularly vulnerable to the destructive action of fluxes, slag, and molten metal. Where reasonable care is not exercised, mechanical abuse can be a significant factor in side wall failure.

In acid practice, the side wall will be silica brick. At least one operator is using a sillimanite plastic for the side wall construction but, due to the initial cost of this material, few such applications could be justified.

In basic practice, complete side wall construction of magnesite brick is generally used. Rather than use this more expensive class of brick up to the roof skew, some operators prefer to limit the application to several courses above the slag line, finishing the construction with silica brick.

A course of neutral chrome brick is recommended between the acid silica and the basic magnesite. The elimination of this course of brick, however, has not proved to be of any serious consequence in actual practice.

Door Arches and Jambs. Since this portion of the refractory construction is, in effect, part of the side wall, it is subject to the same factors affecting the life of the side wall above the metal line. In addition, door arch and jambs must also withstand thermal spalling.

General Refractory Uses

In general, the refractory used for the side wall construction will also be used for the door arch and jambs. In furnaces of 1000-lb. rated capacity or larger, super-duty brick or sillimanite are sometimes used to take advantage of the spall-resistant characteristics of these materials.

On units of under 1000-lb. rated capacity, it is not particularly practical to construct the door arch and jambs of a material different from that used in the side wall. Where door arch and jamb maintenance is a particularly serious problem, the use of water cooling in place of the refractory should solve the problem. However, this type of construction in the foundry-size units has not found application to date.

General. Before leaving the subject of the direct-arc furnace, it might be pertinent to call attention to the unnecessary damage that is done to side wall and roof refractories from the use of high-tap voltage at the start of the melt down.

It is debatable that any time benefit is actually gained by starting

the furnace on high tap but, even conceding that very questionable point, it is safe to say that any saving in time is made at a cost out of proportion to the resulting damage to the exposed refractories. The use of intermediate tap until the electrodes are buried in the charge will pay worthwhile dividends in prolonged refractory life.

High Frequency Induction Furnace

By comparison with direct-arc furnace melting, the tonnage of foundry steel melted in this type of unit is small. Also, by comparison with the direct-arc furnace, the high frequency induction furnace is a small consumer of refractories. However, the refractory problems encountered are of no less consequence.

The refractory material used to form the crucible must have good hot strength, not only to meet the service conditions imposed, but also because the refractory crucible thickness must be kept at a minimum in order to realize the highest possible electrical efficiency.

The refractory crucible must also withstand the fluxing action at the metal line, as well as erosion throughout the crucible depth. These conditions are aggravated by the continual self-stirring action of this type of melting unit.

In commercial size units, the crucible will be either a rammed ganister or a rammed mixture of fused alumina and magnesite. The material used will, of course, depend upon whether the process is acid or basic practice.

Rammed Linings

In acid operation, it has been reported that a rammed sillimanite lining is outlasting silica three to one. This application of sillimanite is very limited, but perhaps a more extended investigation might be worthwhile in acid practice.

The use of preburned crucibles is limited to the laboratory size units due to the difficulties of manufacturing and handling such a crucible. Where a preburned crucible is used, the space between the crucible and the coil is packed with magnesia, fused alumina, or silica sand. Zircon sand also is reported to have been successfully used for such application*.

While the crucible construction represents the major refractory application, there are two other applications which warrant attention. One of these is the use of a plastic material for coating the inside surface of the copper coil prior to the installation of the crucible.

This material should have good air-setting properties and a high specific resistivity factor. It also is important that the material withstand any tendency to crack. The thickness of this lining will be approximately ¼-in. This refractory serves as a protection to the copper coil in the event of crucible failure during operation, and also serves to give rigidity to the copper coil.

The second minor refractory consideration is the use of a refractory to form the lining above the slag line, including the spout. This portion of the furnace is subject to serious mechanical abuse, as well as to metal erosion when the furnace is tapped.

Mechanical Strength

Since the refractory used for the construction of this part of the furnace is not subject to sufficient temperature for any period of time to develop a good ceramic bond, it must have good cold-setting properties to provide the necessary mechanical strength. The material used must also be sufficiently refractory to withstand the temperature of the molten metal while the furnace is discharged. A sillimanite plastic will very satisfactorily answer all the requirements of the refractory in this application.

Homemade mixtures of either basic or siliceous materials with sodium silicate or high temperature fireclay cement can also be used. While this latter practice is an inexpensive solution, it is questionable that the service is comparable to that obtained from the sillimanite material.

Ferrous foundry operators have found this melting unit to fill a definite need in certain classes of work. Its use in ferrous melting operations has grown markedly during the past 12 or 15 years.

As melting operations for iron and steel are carried on at greater temperatures than are normally used in non-ferrous work, the refractory manufacturer has been faced with a real problem to develop an all-around good refractory.

Refractories for these melting units must be able to withstand chemical attack, erosion, thermal and structural spalling and, to some degree, mechanical abuse. Likewise, they must have a high fusion point.

While all portions of the lining are subjected to extreme temperatures, those parts that are washed by the metal as the furnace rocks do not suffer particularly from excessive heat. However, this advantage is overcome by the erosion resulting from the washing action of the metal bath.

Thermal Shock

The whole furnace lining is subjected to thermal shock during shutdown periods. This can be minimized if care is taken to keep the furnace closed as tightly as possible after the power is cut off. Thermal shock is always a hazard around the door, even during operating periods.

Chemical attack, while not pronounced if care is taken to charge relatively clean scrap, is always present to a degree. Most operations are carried on without slagging. Thus the only slag produced is that formed by reactions between foreign material in the charge and the refractory.

This slag is quite viscous and, except for the rocking action, might otherwise serve as a protective coating on the lining. In normal operating procedures the furnace atmosphere is relatively clean and contributes very little toward lining destruction.

Where the furnace is used in duplexing operations, high power inputs are not necessary. Under such conditions lining life is much improved over cold melting practice.

Selecting Refractories

As in all electric melting operation, it is difficult to conceive of a fully satisfactory refractory for this service. Basic brick will not do for reason of their high thermal expansion and poor spall resistance. Silica fails to meet the requirements for the same reason.

Fireclay refractories fail in cold melting because of their wide softening range and poor chemical resistance. In duplexing operation, superduty fireclay products often do a

*G. F. Comstock, "Lining a Small Induction Furnace," *Metal Progress*, Dec., 1939.

very excellent job, and in some instances do a fair job where cold melting is practiced.

Most operators have found that sillimanite or mullite types of refractories give the best and most economical service in the long run. Their high melting point without a wide softening range, plus their exceptional resistance to spalling, coupled with better than usual resistance to fluxing, make them most fitted for this application.

Even so, some operators find that it pays to balance out the lining life by the use of silicon-carbide refractories as door blocks. Some also use aluminum-oxide refractories for electrode sleeves, but the advantage of this is debatable.

Zircon refractories are now being used as linings in the indirect-arc rocking furnace. The application has been limited so far, but the results are quite encouraging. They are extremely refractory, but the resistance to spalling is somewhat lower than that of sillimanite or mullite.

This factor is overcome by using sillimanite door shapes. With this combination it appears that double lining life is assured. Since the cost of zircon is approximately twice that of sillimanite, the principal saving is in the cost of labor and a reduced number of shut downs for relining.

More development work is necessary before one can be assured that zircon will be the most economical lining for the indirect-arc rocking furnace in all ferrous melting operations; where lining life is not satisfactory it would certainly be worth investigating.

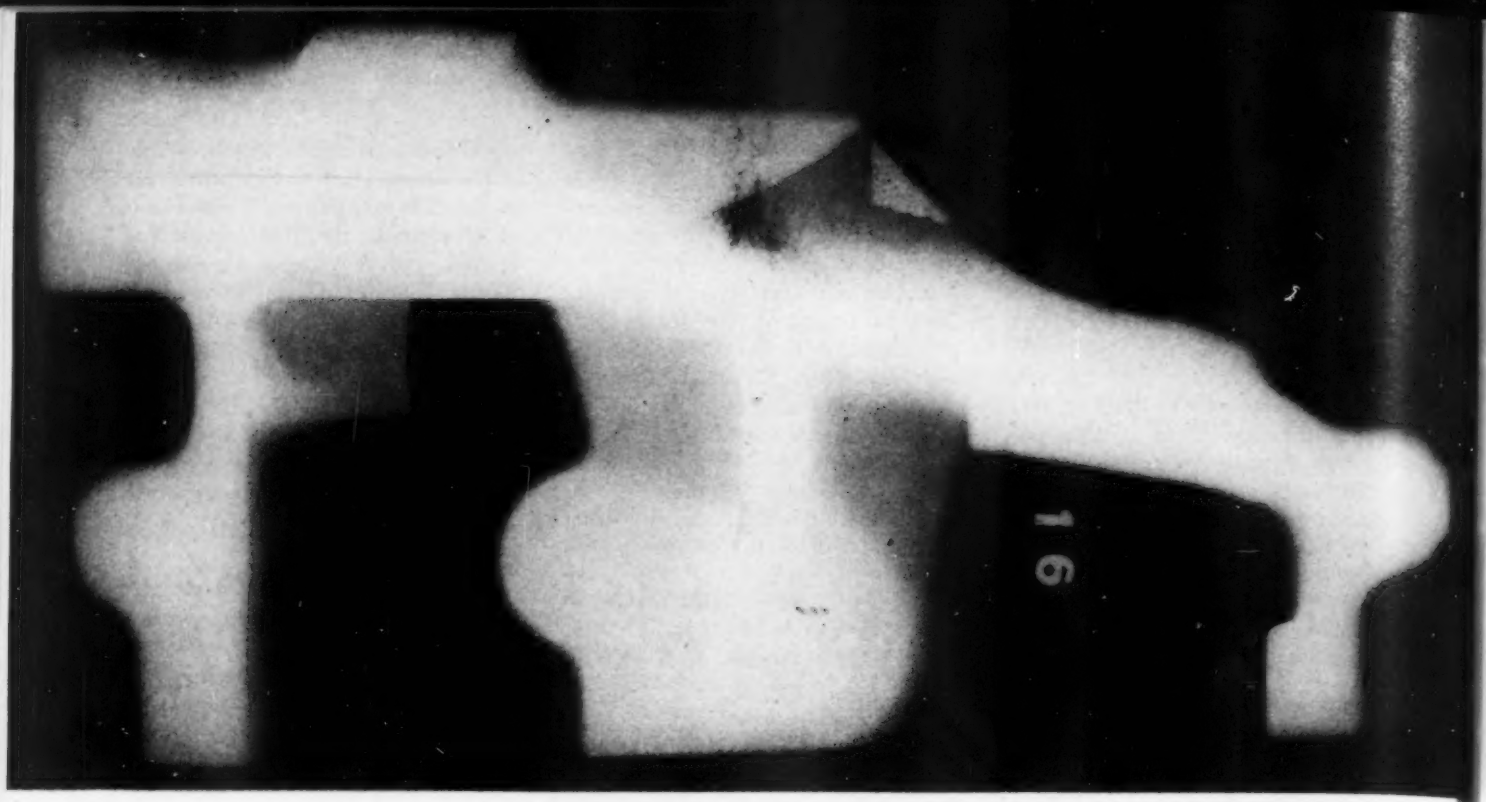

Fig. 5—Radiograph showing shrinkage zone in section of intake rocker box from an air-cooled cylinder head casting.

DENSITY OF Light Alloy Castings

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• *This paper discusses the possible errors involved in the use of density determination for measuring the soundness of castings. It suggests some methods for reducing these errors to a minimum and illustrates the application of the methods. Some observations are made on the practical significance of variations in density of castings.*

DENSITY determinations have long been used in the copper industry as a measure of the soundness of castings. The literature abounds in references describing investigations in which the densities of copper and copper alloy castings vary over ranges as high as 8 or 10 per cent. Density determinations are also made as a matter of routine in some plants producing copper and copper alloy ingots for working.

It is generally agreed, at least in the literature, that the sources of unsoundness in copper castings are shrinkage and the evolution of gas during the solidification of the metal.

Aluminum alloy castings are known to suffer from unsoundness due to the same causes. By analogy, it would appear that density determinations might be of use in the examination of the soundness of aluminum alloy castings.

The principal non-destructive method in use at present for the determination of the soundness of aluminum alloy castings are radiography and fluorescent oil-black light examination.

Radiography is probably the most generally useful of the non-destructive tests. It has the advantage of defining the voids as to size and location, but has the drawback of relatively high cost and a sensitivity which is limited to about 3 per cent of the section thickness being examined. Also, radiographic examination does not yield quantitative values which may be used as an independent index of soundness.

Examination by the fluorescent oil-black light procedure is limited to the determination of voids which have an opening to the surface of the object being examined.

Preliminary determinations on miscellaneous aluminum alloy sand castings indicated variations in density of up to 3 per cent. Since the density determination, even on relatively large objects, generally can be made with an accuracy of at least 0.1 per cent, using the usual method of weighing the specimen in air and suspended in a liquid, it appeared that density determinations might be useful in laboratory investigations and, perhaps, under

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some conditions, even for commercial inspection. It immediately becomes desirable to determine the limits of significant measurement.

Determination of Density

The density determinations in the investigations to be described were made on four balances of 0.4-, 1.5-, 5- and 35-lb. capacity, respectively. With each specimen the balance of smallest possible capacity was used. The precision of the balance was such that the ratio of the mean weight of a specimen, observed in repeated weighings, to the maximum deviation from the mean was in no case less than 4000 to 1.

With a given balance, the ratio decreases with the weight of the specimen. Consequently, the precision of the balance must be such that a ratio of at least 4000 to 1 is obtained with the lowest weight of specimen for which the balance will be used. These conditions confine the expected variations in repetitive weights to within 0.025 per cent, which is adequate to permit keeping the maximum error in the density determination below 0.1 per cent.

The immersion liquid used was a 0.04 per cent solution of a wetting agent in tap water. The wetting agent is quite necessary, otherwise difficulties are encountered because of air bubbles clinging to the castings. The immersion liquid was maintained within 5° C. of a specific temperature and all determinations reduced to a standard temperature.

The volume coefficient of thermal expansion of the alloy being investigated, and the temperature coefficient of density of the immersion liquid are, of course, necessary for the reduction of determinations to a standard temperature.

Determination of Void-Free Density

For the determination of the volume of voids in a casting, it is necessary to know the density of the casting if free from voids. The determination of the void-free density of a specific casting is a somewhat complex problem. It is not sufficient to determine the density of a single void-free specimen of a standard alloy experimentally, and use the value obtained as the established density of the alloy.

The effect on density of variations in composition among random castings, within acceptable specification limits, would introduce intolerable errors. For example, with 195 alloy the permissible variation in composition within the Army-Navy Aeronautical Specification AN-QQ-A-390 would make possible a variation of 1.63 per cent in density, which is more than half the expected maximum variation in density in commercial sand castings of this alloy.

If the average chemical composition of a casting is accurately known and the void-free density is calculated by the formula for the density of mixtures, assuming that the alloy is merely a mixture of its constituent elements, the density so calculated is, in most cases, lower by a few tenths of a per cent than the density determined on a specimen of the same composition which has been forged or otherwise worked to a reduction of 80 per cent or more.

This difference results from the contraction in volume which usually accompanies the alloying of two or more metals. The calculated density can be satisfactorily adjusted to actual void-free density by applying a correction factor based on an experimental determination on a worked specimen of the alloy.

Once the proper correction has been established for any specific composition within the specification limits of a standard alloy, that correction can be used without objectionable error for any other analyzed heat of that alloy, in view of the relatively small variations in composition within specification limits. Unfortunately, in most production procedures the exact chemical composition of each specific casting is not known, even though the routine does insure each casting being within specification limits.

Void-Free Specimen

The shortcomings of the foregoing described methods of establishing the void-free density of a casting led to the development of a procedure which was utilized in these investigations. A portion of the same batch melt, well stirred, from which the casting is made is poured into a small metal mold of such design that the casting is practically free from voids.

Figure 1 illustrates a casting made in a mold which has been found satisfactory for standard density specimens. For an even higher degree of accuracy, such a standard

Fig. 1—Density cone casting showing density specimen before and after hot pressing. Outlined section indicates part used as density specimen.

density specimen may be hot pressed or otherwise worked to eliminate any small amount of voids. Experience with many hundreds of these standard density specimens indicated that, even without pressing, they rarely contain more than 0.15 per cent voids.

The standard density cone, or specimen, is, in most cases, poured at the same time as the casting on which the void determination is to be made, but in some cases it is poured from a remelt of the whole casting. The remelt of part of a casting cannot be used for a standard density specimen to represent the whole casting without danger of serious error from segregation.

Complex Castings

With a complex casting involving many differences in section, and thus markedly different solidification rates, variations in copper concentration as high as 0.75 per cent may occur in the case of aluminum alloys containing 4 to 8 per cent of copper. For the same reason, the analysis of filings or machinings from a casting cannot be used for an analysis upon which to base a calculation of void-free density.

In utilizing the standard density specimen for the establishment of the void-free density of a specific casting, possible error from variation in microstructural condition between the standard specimen and the casting must be considered.

The density of an aluminum alloy varies with the distribution of the alloy elements between the aluminum solid solution and the precipitated form of the specific elements. Such variations in density may amount to as much as 0.5 per cent, but can be completely eliminated by determining the density of both the casting and its accompanying standard specimen in the annealed condition.

By properly recognizing the previously discussed sources of error, percentage void determinations can be made with a total maximum error of 0.2 per cent. The usual or average error would be much less than this, perhaps 0.06 per cent. This order of error appears to be satisfactory for the examination of light alloy castings.

The determination of the practical significance of variations in density of commercial castings is not simple. A number of approaches to the problem have yielded useful data from which a fairly satisfactory picture of general effects can be constructed; however, it must be confessed that the assignment of quantitative values to the various factors involved is, as yet, impossible.

Molding Method

In one investigation, 88 specimens of a cylinder head casting for an air-cooled radial aircraft engine were examined. These castings were all from a pattern which had been in fairly large production for a considerable period of time. The castings were made in dry sand molds by methods which have become conventional for this type of production.

The casting was molded in a vertical position, the open end up and the rocker boxes down. A ring riser extended upward from the flange, with enlargements over each of the rocker boxes. The molten metal was poured from two hand ladles simultaneously directly into the risers.

All of the 88 specimens had been scrapped for mechanical reasons, such as core shift, accidental undercutting during cleaning, etc. The castings were numbered arbitrarily from one to eighty-eight, and the density of each determined as described in the foregoing paragraphs. The void-free density of each head was determined by remelting each casting separately and pouring a density specimen from every melt.

The density standard specimens were also hot pressed to insure the elimination of such voids as might be present in the small chill-cast specimens. The results of these determinations are presented in Fig. 2, bottom line of graph. It will be noted that the voids varied mostly between 0.90 per cent and 1.85 per cent, with three castings below and five above this range.

It has become a fairly general practice with aircraft engine manufacturers to specify the maximum amount of visible pinhole porosity which is acceptable on machined surfaces of this type of casting. In a common method of producing the castings, the open or barrel end is upward in the mold, and a continuous riser connects to the open end.

Pinhole Porosity

Some manufacturers judge the amount of pinhole porosity in a specific casting by very carefully machining the bottom surface of this ring riser and visually estimating the amount of pinhole porosity by comparison with accepted standards. A similar rating was made on each of the 88 cylinder heads by cutting the flange section from the cylinder head and machining the surface which would be adjacent to the ring riser, followed by comparing the porosity visible on the machined surface with arbitrary standards numbered from one to twelve.

The flange sections were also

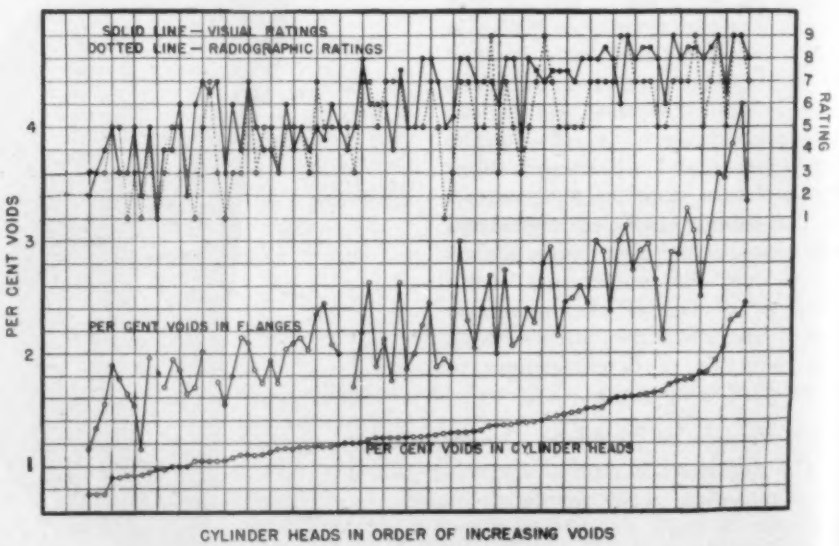
SOLID LINE — VISUAL RATINGS
DOTTED LINE — RADIOGRAPHIC RATINGS
PER CENT VOIDS IN FLANGES
PER CENT VOIDS IN CYLINDER HEADS
PER CENT VOIDS
RATING
CYLINDER HEADS IN ORDER OF INCREASING VOIDS

Fig. 2—Correlation of percentage of voids in 88 aircraft air-cooled cylinder head castings with percentage of voids in the flanges, with radiographic porosity ratings of the flanges, and with visual porosity ratings of machined surfaces of the flanges.

radiographed, as is done by other manufacturers, and the percentage of voids determined separately for each. It will be noted from Fig. 2 that there is a general correlation between the percentage of voids in the cylinder heads, as a whole, and the percentage of voids in the flanges, the visual ratings of porosity on machined surfaces and the radiographic ratings, in that the trend curves for all four examinations are roughly parallel. However, the correlation between individual specimens in the four types of rating is not impressive.

To further examine the distribution of voids in these 88 castings, a number were sawed into sections, as indicated in Fig. 3. Figure 4 illustrates diagrammatically the variation in percentage of voids in the separate sections of six of the castings. The voids in all of the sectioned castings followed the same general distribution. The uniform pattern of distribution of the voids in each head testifies to the absence of substantial amounts of segregated voids.

The separate sections of the 19 sectioned heads were radiographed to further search for segregated voids. The only localized unsoundness found was shrinkage in some of the web sections of the intake rocker boxes. This type of shrinkage is illustrated in the print from the radiograph, Fig. 5. This was the most extensive area of localized unsoundness found in the web sections radiographed.

The percentage of voids in the entire casting, No. 16, was 0.95 per cent, and the percentage of voids in the intake rocker box section was 1.1 per cent. A per cent void determination in the section of the intake rocker box containing the shrinkage showed that the shrinkage accounted for only 0.10 per cent voids in the rocker box and 0.01 per cent voids in the whole head.

It must be concluded, therefore, that the principal significance of the variation in voids in this lot of cylinder head castings is that it reflects the variation in general pinhole porosity. It is known that the principal factor in the formation of general pinhole porosity in aluminum alloy castings is the concentration of gas in the melt.

To further determine the variation in percentage of voids in commercial light alloy castings, a number of castings were taken at random from production and the percentage

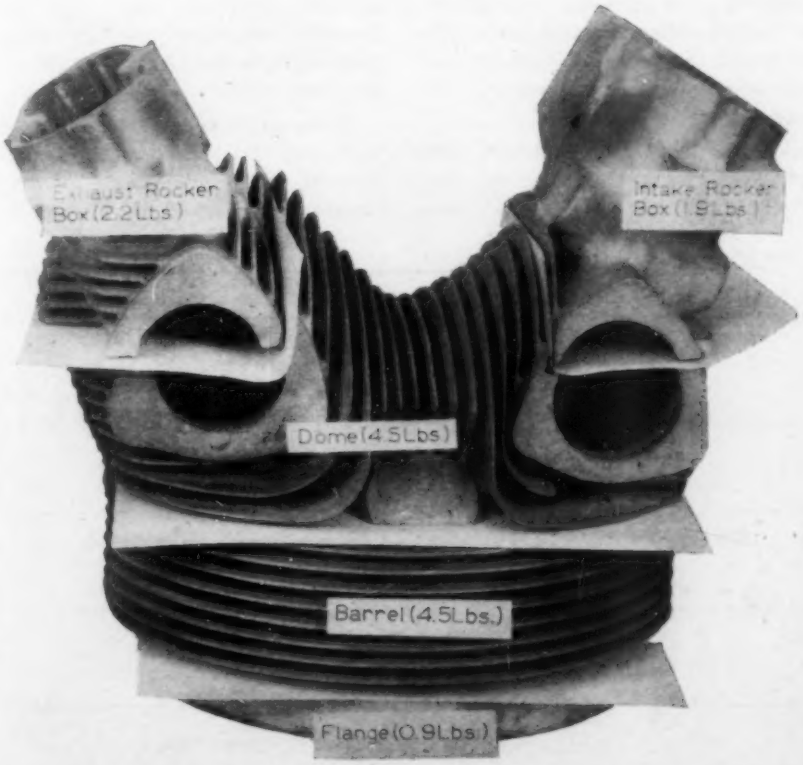

Fig. 3—Aircraft air-cooled cylinder head casting sawed into five sections for determination of the distribution of voids.

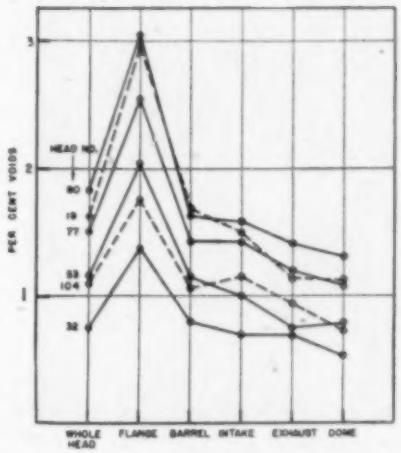

Fig. 4—Sketch showing percentage of voids in various sections of six aircraft air-cooled cylinder head castings.

of voids determined. The results are given in Table 1. Aluminum sand castings and semi-permanent mold castings appear to have about the same average percentage of voids.

The aluminum permanent mold castings are definitely lower in voids than the sand castings, in agreement with general experience. The die castings contain substantially more total voids on the average than the other types of castings. Unfed shrinkage voids and entrapped air are probably responsible for this effect, which is more marked with magnesium than with aluminum.

The magnesium base alloy castings are interesting in that the sand castings have the lowest average percentage of voids, being considerably lower than the average percentage of voids of any of the types of aluminum castings. The magnesium alloy permanent mold castings contain generally somewhat more voids than the sand castings but, here again, the magnesium alloy castings are lower in percentage of voids than the aluminum alloy castings.

However, the magnesium die castings contain more voids than any of the aluminum castings. It has been long observed that magnesium castings usually contain no general porosity arising from the precipitation of gas during solidification, and that any voids present are caused by localized shrinkage. The data in Table 1 support this view.

It has been observed that the amount of general porosity visible on the machined surface of aluminum alloy castings varies inversely with the rate of solidification

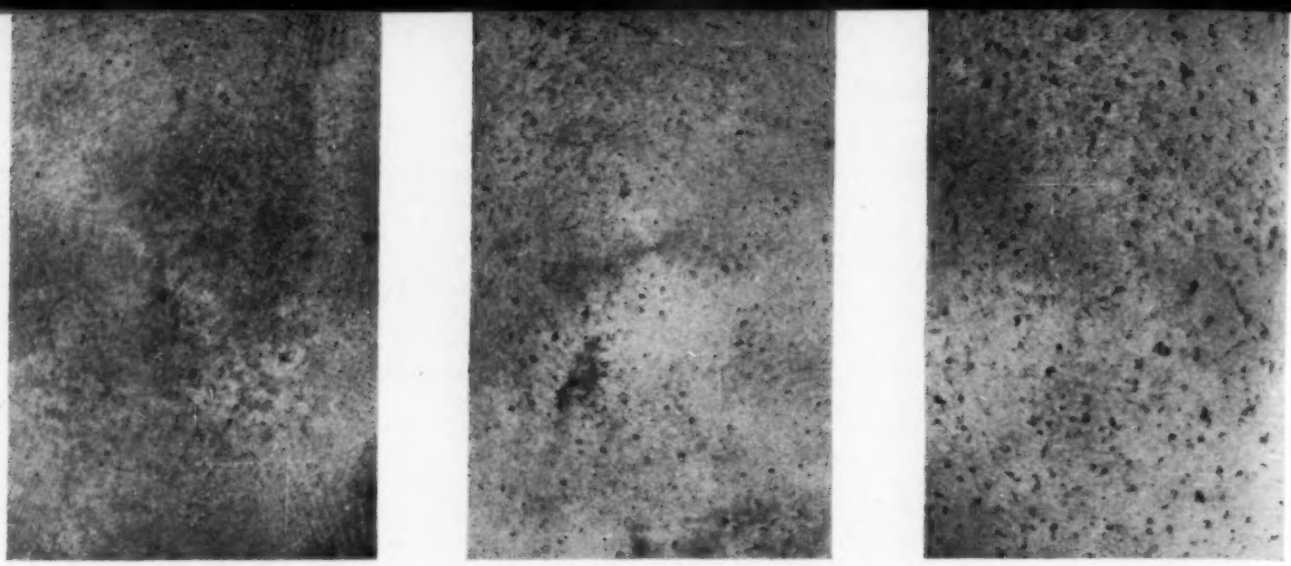

Fig. 6—Three sections from an aluminum alloy sand casting. Surfaces are specially machined to fully reveal porosity. (Left) ¾-in. section, 0.68 per cent voids. (Center) 1½-in. section, 1.32 per cent voids. (Right) 3-in. section, 2.52 per cent voids.

of the sections. Thus, heavy sections in a casting usually show more pinhole porosity than thin sections in the same casting, and permanent mold castings generally show much less pinhole porosity than sand castings.

This is illustrated by Fig. 6, which shows the appearance of the machined surface of a ¾ in. thick, a 1½ in. thick, and a 3 in. thick section from the same sand casting. It will be noted that the percentage of voids varies in the same way as the amount of visible pinhole porosity. High rates of solidification appear to inhibit the precipitation of gas during solidification of aluminum alloys.

It is suggested that similar effects obtain in copper base alloy castings where, as demonstrated by Rowe,[1] 5 per cent of voids may be present in bronze sand cast gear wheels, while similar castings more rapidly cooled, as when made in permanent molds or by the centrifugal process, will contain not more than about 1 per cent of voids.

Effect of Variation in Density on Mechanical Properties

In one experiment, standard tensile test specimens and fatigue test specimens were cast from the same lot of 355 alloy, three portions of the melt having been treated in such manners as to give rise to a different concentration of gas in each. All specimens were heat treated to approximately the commercial T6 condition.

The results of the tensile tests and the void determinations on the fatigue specimens are given in Table 2. The results of the fatigue tests are shown in Fig. 7. The fairly wide variation in percentage of voids brought about no significant variation in mechanical properties.

In the foregoing series of fatigue tests, the test sections of the specimens were not machined. In another series of fatigue tests, the results of which are given in Fig. 8, the test sections were machined all over, and here, in some ranges of stress, the specimens with the higher volume of voids gave somewhat lower fatigue properties.

However, even in this series of tests the difference in fatigue strength between high and low porosity specimens is not much greater than the general scatter in any one series.

In a series of full scale fatigue tests on cast cylinder heads performed under conditions of temperature and stress distribution ap-

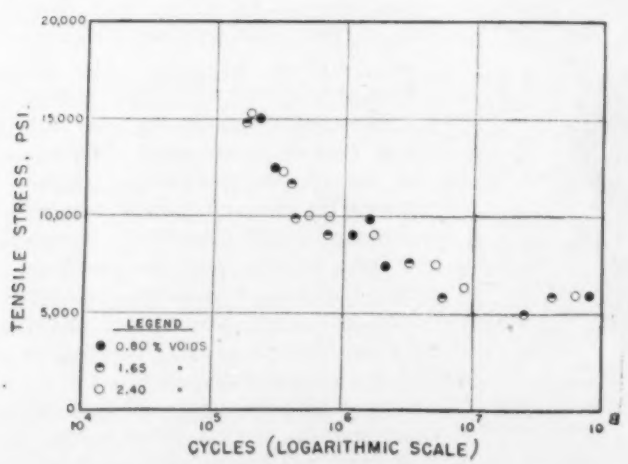

Fig. 7—Results of direct stress fatigue tests of sand cast specimens of 355-T6 alloy. Test section, ¼ in. x 7½ in. with as-cast surface Minimuir. stress = zero.

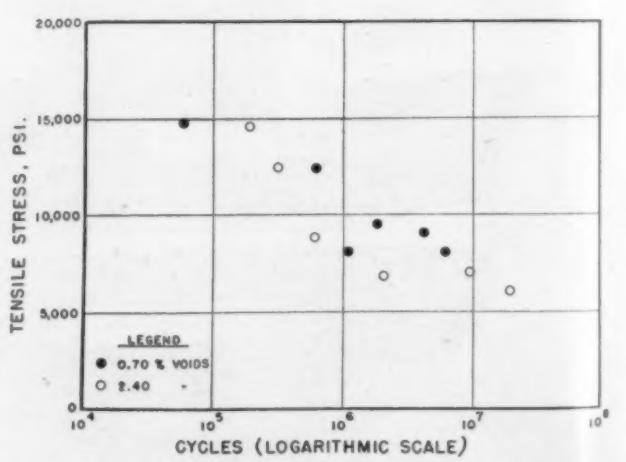

Fig. 8—Results of direct stress fatigue tests of sand cast specimens of 355-T6 alloy. Test section, ¼ in. x 5½ in. with machined surface. Minimum stress = zero.

Table 1

Percentage of Voids in Commercial Light Alloy Castings

Base of Alloy	Type of Casting	No. of Castings	Weight Range, lb.	Voids, per cent Max.	Min.	Ave.
Aluminum	Sand	37	0.7-82	3.00	1.11	1.82
Aluminum	Permanent Mold	27	0.7- 2	1.84	0.34	1.15
Aluminum	Semi-perm. mold	7	3.0-67	2.52	1.40	1.89
Aluminum	Die	20	0.26-0.54	5.70	0.64	3.12
Aluminum	Continuous Ingot	5	16 to 24 in. sq.	0.64	0.32	0.49
Magnesium	Sand	15	1.0-49	0.54	0.00	0.28
Magnesium	Permanent Mold	12	0.7-39	1.16	0.27	0.49
Magnesium	Die	10	0.9-2.6	17.40	3.79	5.97

proximating that occurring in the operation of radial aircraft engines, variations in voids of from 0.71 per cent to 2.60 per cent were found to have no significant effect on fatigue life.

It is perhaps not too surprising that this should be so. An effect greater than about 3 per cent reduction in mechanical properties is not to be expected unless some notch or stress concentrating feature accompanies the reduction in section corresponding to the volume of voids. In the application of most castings, it is doubtful whether normal variations in dimensions, design, assembly and other structural features are reproducible within 3 per cent.

Summary and Conclusions

The volume of voids in light alloy castings can be practically determined to within 0.2 per cent by density measurements, providing proper precautions are taken in the determination of the void-free density from the standpoint of segregation, and the relative microstructural conditions of the casting and the void-free density specimen.

A practical method of determining the void-free density is to cast a small standard specimen from the same melt under such conditions that its concentration of voids will be very low. Subsequent working of this specimen, usually at elevated temperatures, will provide a void-free standard with which the density of the casting can be compared.

Variations in density of aluminum alloy sand, permanent mold, and ingot castings are caused principally by variations in general gas or "pinhole" porosity. Usually the shrinkage zones do not constitute a sufficiently large volume to markedly affect density determinations. The voids in commercial sand castings normally vary from 1 to 3 per cent, and in permanent mold castings from 0.3 to 2 per cent.

In magnesium alloy castings, the relatively smaller total concentrations of voids, as indicated by density measurements, is due to the absence of gas porosity. Such variations in density as occur are generally the result of local shrinkage.

The relatively large concentrations of total voids in die castings, both aluminum and magnesium base, are undoubtedly due to the trapped air which is a concomitant of the process.

The effect of gas porosity on the mechanical properties of castings is probably generally not greater than the corresponding reduction in section. In aluminum alloy sand and permanent mold castings, the effect of this reduction in section is usually overshadowed by larger variations in other factors affecting the effective strength of the section.

Although density determination has been demonstrated to be a useful tool in the investigation of light alloy melting and casting technique, it appears to be of doubtful potential utility as a means of general inspection because there has not yet been established any correlation between density variations and engineering or service characteristics.

Table 2

Mechanical Properties of ½ In. Diameter Sand Cast Test Bars of 355-T6 Alloy Cast from Melts of Various Gas Concentrations

Gas Concentration	Voids in Fatigue Specimens, per cent	Yield Strength, psi.	Tensile Strength, psi.	Elongation in 2 in., per cent	Brinell Hardness, 500-kg. load, 10-mm. ball
Low	0.80	29,450	36,350	2.0	90
Medium	1.65	28,740	36,670	2.3	89
High	2.40	29,850	35,800	1.7	88

Reference

1. F. W. Rowe, Bronze Worm-Gear Blanks Produced by Centrifugal Casting," *Journal*, Institute of Metals, vol. 36, p. 191 (1926).

Cleanliness and Safety in the Foundry

By James Thomson, Chief Works Engineer,
Continental Foundry & Machine Co., East Chicago, Ind.

• Foundry cleanliness—its importance in promoting safety and in effecting foundry operating economies—prompts the presentation of this article, originally published in "Safety Engineering," Sept., 1944, issue.

IN THE face of a serious manpower shortage, the need for continued study and improvement of foundry practice becomes a matter of utmost consequence. In order to maintain production at high efficiency, operations which may be responsible for flawed or faulty castings must be weeded out and carefully scrutinized for means of improving them.

In realization of these facts, a survey was made of this foundry to reveal those operations which could be considered of questionable efficiency, and where improvement would have a beneficial effect on production, either by reducing or eliminating rejected castings, or by better utilization of manpower.

Back Where They Started

One operation which attracted immediate attention was the practice of cleaning sand molds by compressed air. Although this method of mold cleaning has been common practice in foundries, it did not require much observation to recognize its shortcomings.

Instead of cleaning the mold, the compressed air stream would scatter the dust particles in all directions. The lighter and finer dust particles were picked up by air currents and carried throughout the plant. The heavier dust particles rapidly settled, only too frequently settling back onto the "cleaned" mold from which they had been blown off, or onto adjacent molds which had previously been blown clean.

Fig. 1—Suction cleaning of large molds.

Large open molds, particularly those having deep and intricate patterns, presented a special problem, because disturbed dust would settle into the deeper cavities of the mold without being readily noticeable. As the operation of blowing molds clean would continue from mold to mold, dust would continue to accumulate in the already cleaned molds, penetrating into the deepest portions.

It was apparent that castings of fine appearance, and smooth, uniform surfaces could not be assured if metal were poured into molds thus "cleaned." A more positive and effective method of cleaning molds was required, and to accomplish this a heavy duty pneumatic

Fig. 2—(left) Smaller mold being cleaned by suction hose.

Fig. 3—(right) Vacuum removal of steel shot from casting cavities after shot cleaning.

cleaning system was installed in the No. 3 foundry.

This system, which is a stationary type of unit, consists principally of a multi-stage centrifugal vacuum producer driven by a 50-hp. motor connected to it by a flexible coupling, a 48-in. diameter combination dust separator of the inverted filter bag type, and three 18-in. diameter primary shot separators. All of the separators have cone hopper bottoms fitted with hinged dust disposal valves.

Vacuum Cleaning a Foundry

The piping system consists principally of three vacuum mains. The longest is 775 ft. in length and extends through the foundry building. The remaining mains are 500 ft. and 150 ft. in length. All three mains run well overhead and out of the way. Drops extend down at strategic points to provide vacuum cleaning connections for the working area of the building.

These drops are spaced so as to permit the area to be adequately reached using convenient lengths of hose. As much as 75 ft. of 1½-in. hose is used. Each drop is terminated with a vacuum hose inlet valve which closes automatically when the hose is withdrawn. As many as ten operators may use this system simultaneously at different areas in the foundry.

With this system, molds are now cleaned by suction. Slender lance-type nozzles, available in lengths up to 6 ft., are used to penetrate deep into the mold design, reaching all surfaces and removing all dust and loose material. Gulper nozzles are used for cleaning molds which have large flat surfaces. For smaller molds, the open end of the hose is used effectively without a nozzle (Figs. 1 and 2).

Cleaning Molds

Dust and foreign matter are drawn rapidly into the vacuum nozzle, conveyed through the hose and piping system to the dust separator where the dust is filtered out of the air and the cleaned air then passes through the vacuum producer and is exhausted into the atmosphere.

Many advantages have been obtained by using vacuum for doing this work. The most important gain, of course, has been the more thorough cleaning of the molds. In addition, there has been a marked improvement in the condition of the plant atmosphere, which no longer is periodically recharged with dust. This cleaner atmosphere not only provides better visibility for the operator, but enables him to work under more healthful conditions.

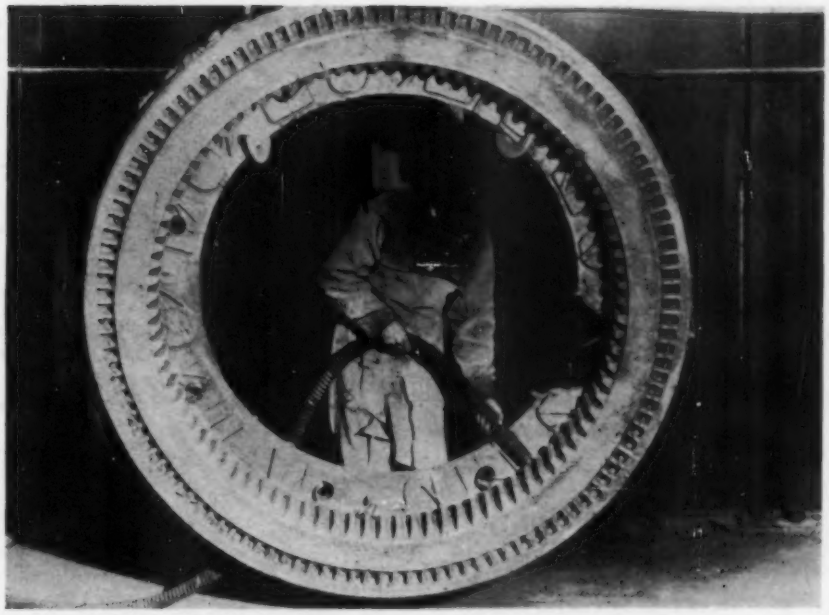

Fig. 4—Another example of steel shot removal from large casting.

Removing Shot

Another interesting and time-saving operation now being done by vacuum is that of removing steel shot from pockets in castings after the castings have been shot cleaned. Removing shot from cavities in castings has always been a slow and time-consuming task, particularly if the shot were lodged in hard-to-reach pockets and corners. Using vacuum, all pockets are thoroughly and rapidly cleaned of shot accumulations (Figs. 3 and 4).

Not only has this application proved a valuable time-saving device, but it has resulted in the recovery of thousands of pounds of shot which otherwise might have been lost.

Special intercepting separators are provided for each of three shot blasting rooms. All shot collected in the area around the shot blasting rooms is intercepted and retained in the separator serving that shot blasting room.

The intercepting separators are designed to allow fine dust and other material to pass through them and to retain only the shot. All dust and other dirt passes through the intercepting separator and is conveyed to the 48-in. combination separator. Other material picked up by the system, as in mold cleaning, also is conveyed to the 48-in. combination which filters the air before it passes through the vacuum producer into the atmosphere.

The same system also is used for general cleaning in the plant, for removing overhead dust accumulations, for cleaning in and around equipment, and for removing all sorts of dust accumulations from floors. Special nozzles are provided for these varied operations. Many other useful applications have been encountered as the system is used.

The installation of this system was the result of satisfactory experience with a smaller 20-hp. system which was installed a number of years back in the No. 1 foundry for somewhat similar operations, but, of course, on a smaller scale.

Not only have these heavy duty vacuum cleaning systems increased the efficiency of many operations, but they have also improved working conditions and brought about appreciable economies by recovering valuable materials.

Acknowledgment

The author wishes to acknowledge the courtesy of United States Hoffman Machinery Corp., Syracuse, N. Y., in furnishing the illustrations.

GRAY IRON
Wear Resistance

• *High wear resistance properties of gray iron are secured under conditions of evenly distributed graphite flakes with a fully pearlitic metal matrix. Hardening by alloy additions or heat treatments further increases wear properties, allowing a wide range for consideration of gray iron as an engineering material.*

By F. G. Sefing,
Research Metallurgist,
International Nickel Co.,
New York

AN outstanding characteristic of gray iron is its wear and galling resistance in metal rubbing applications such as cylinders, piston rings, machine tool ways, bearings, etc. This property is generally recognized as resulting from the lubrication offered by the widely distributed graphite in gray iron.

Figure 1 illustrates different graphite structures in gray iron. Figure 1A illustrates a random and even distribution of graphite. Figure 1B shows small graphite flakes in a regular pattern with more or less uneven distribution. Figure 1A iron yields superior wear performance, and Fig. 1B inferior wear.

In machined gray iron surfaces, graphite particles and metal matrix are exposed to the mating metals. The photomicrographs of etched gray irons in Fig. 2 illustrate the condition of such surfaces in different irons. Obviously, since the metal and graphite are in contact at the bearing surface, it is expected that the condition of the metal matrix would have some influence on the wear and galling quality of the iron.

The factors, therefore, which influence the degree of wear and galling resistance of gray iron are explained as follows:

1. The greater amount of graphite with optimum size and distribution, the better wear and galling resistance offered. Very fine graphite particles and uneven distribution offer essentially reduced graphite bearing to the mating surface. For example, the iron shown in Fig. 1B would offer less bearing properties than Fig. 1A iron.

2. The condition of the metal matrix affects wear properties. For optimum wear resistance, the metal matrix should be pearlitic, as shown in Fig. 2A, with random, well-distributed graphite. Structures containing soft ferrite (similar to low carbon steel) are inferior to those free of this constituent (see Figs. 2B and 2C).

Furthermore, when these ferrite particles are small and surrounded by graphite (Fig. 2B) the wear and galling properties are exceedingly poor. The presence of free carbides (Fig. 2D) reduces wear life. These carbide areas are hard and abrasive to the metal against which they rub.

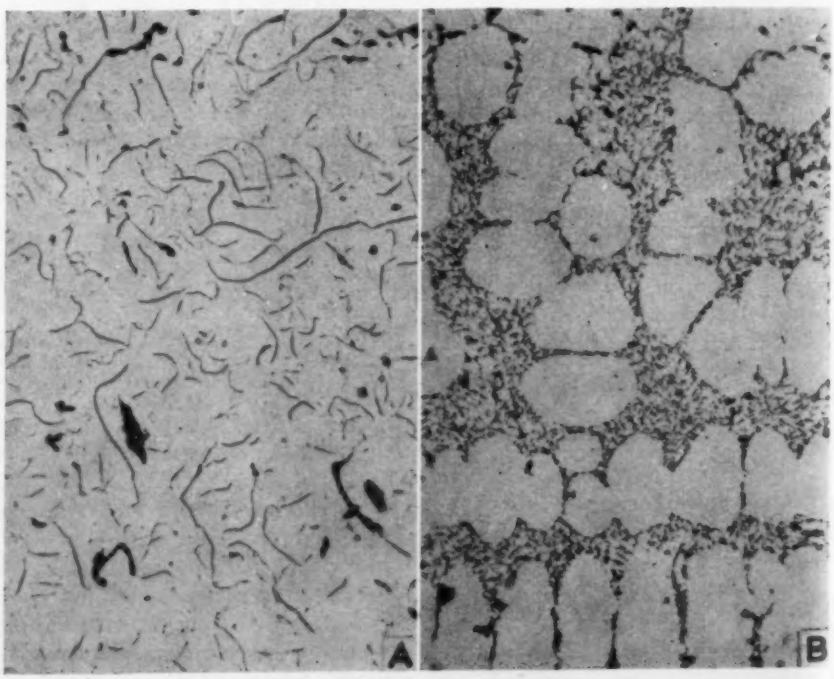

Fig. 1—Graphite in gray iron. (A) Graphite flakes randomly and evenly distributed, "A.F.A. Type A." (B) Small flakes following a pattern and showing some uneven distribution, "A.F.A. Types D and E." Unetched, 100 ×.

This paper was secured as part of the 1945 "Year-'Round Foundry Congress" and is sponsored by the Gray Iron Division of A.F.A.

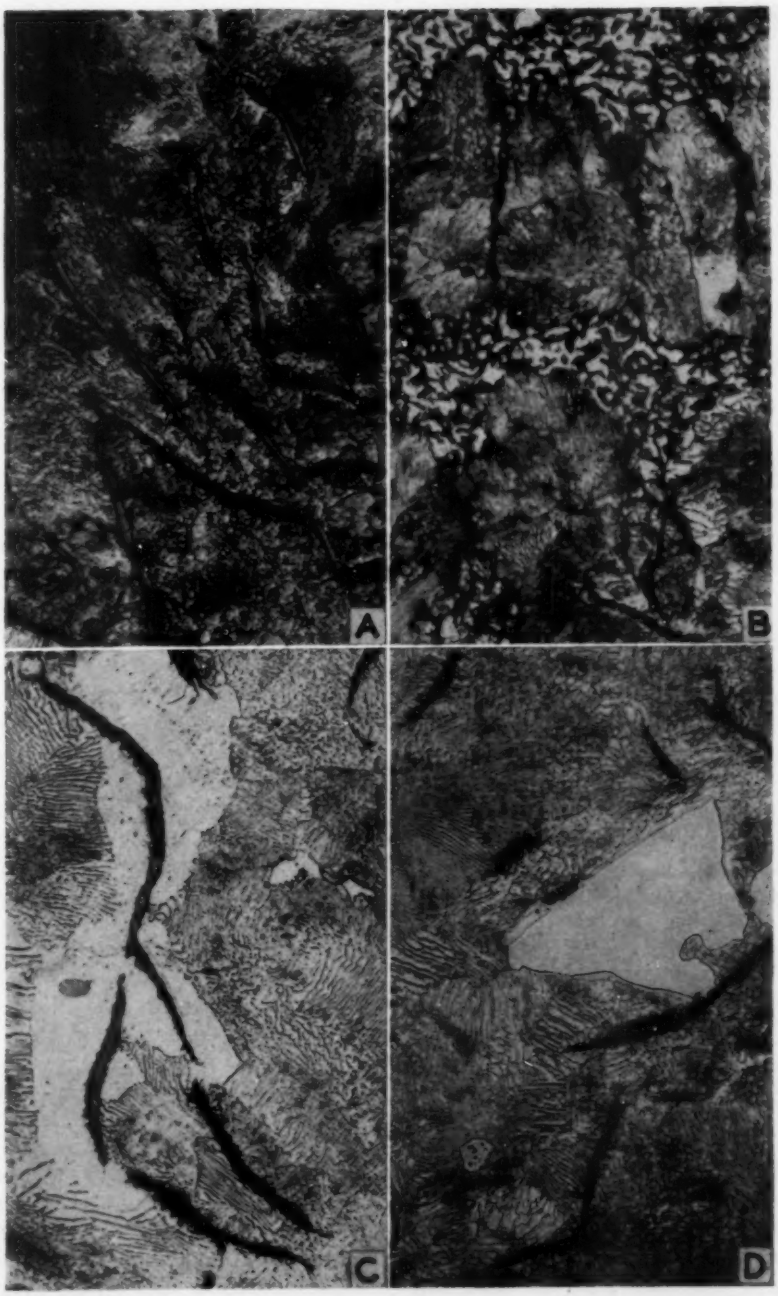

Fig. 2—Structure of metal matrix in gray iron. (A) Metal fully pearlitic. (B) Corresponding to Fig. 1B, ferrite (white) with small graphite particles. (C) Soft gray iron with large areas of ferrite lying next to graphite. (D) Hard gray iron with excess of hard cementite (white). Etched, 500 ×.

3. Combining paragraphs 1 and 2, therefore, that gray iron offers the best wear and gall resistance which has random, evenly distributed graphite with no free ferrite or cementite in the metal matrix (Figs. 1A and 2A).

4. Increasing hardness improves wear resistance of particular irons. For example, a good gray iron, described in paragraph 3, can be improved in wear resistance by raising the hardness either by alloy additions or by hardening heat treatments. Examples of alloy hardened gray irons are forming dies, machine tools, etc. Examples of heat treated gray iron are hardened cylinder liners, flame-hardened rolls, etc.

5. Limits of applications of hardened wear resistant gray irons should be regarded in the light of the application considered. In metal to metal wear applications, such as pistons, rings and cylinders, the hardened cylinder would impose all of the wear on the rings and pistons, presumably of a lower hardness. This may be desirable since the rings and pistons are more easily renewed.

In hardening gray iron forming dies, rolls, etc., a high order of wear resistance is desirable, while at the same time providing the good rubbing characteristics of gray iron against the metal being formed by these parts.

Gray iron has outstanding wear and galling resistance because of the interspersed graphite. The optimum of wear properties of gray iron can be achieved by having random, evenly distributed graphite with the metal matrix fully pearlitic. Still greater wear resistance of gray iron can be secured by increasing the hardness by alloy additions or by hardening heat treatments.

Combustion Method for

SULPHUR DETERMINATION

in White Cast Iron

James Hedberg, Research Chemist, and H. A. Schwartz, Manager of Research,
National Malleable and Steel Castings Co., Cleveland

• *Malleable iron foundries . . . combustion method for sulphur determination adapted to works control . . . accurate results obtained in 12 minutes.*

RESULTS of sulphur determinations made by the standard rapid method most commonly used today have long been recognized as unreliable. However, the evolution-titration method has continued in vogue because it is rapid and requires no special equipment. Low and non-reproducible results often encountered with alloy and white irons can be obviated to some extent by annealing the sample, but this more than doubles the time for a determination and does nothing to minimize errors inherent in the analytical procedure.

Combustion methods, which have become increasingly popular because of speed and accuracy, were examined with the idea of developing a procedure suitable for works control in malleable iron plants. An accurate result, obtained by the method described, is available in a total time of 12 min.

Methods Investigated

In the program for determining sulphur, in white cast iron, by combustion, several methods were investigated. Two iodate methods having been discarded, a method suggested by G. M. Guiler of this laboratory was tried. Based upon information obtained in an abstract* in *The Engineers Digest,* p. 187, Feb., 1944, the procedure involved the use of a silver nitrate solution as an absorbent.

In this method the sulphur dioxide gas formed, when the sample is ignited at a high temperature in an oxygen atmosphere, is absorbed in a neutral silver nitrate solution. With water, sulphur dioxide forms sulphurous acid which reacts with silver nitrate to form an equivalent amount of nitric acid. This is illustrated by the following equation:

$$H_2SO_3 + 2AgNO_3 \rightarrow Ag_2SO_3 + 2HNO_3$$

Titrating the liberated nitric acid with a standard sodium hydroxide solution gives an index of the sulphur content of the sample.

Equipment Required

The apparatus required is very simple but the method may perhaps be adapted to more elaborate equipment on the market. An ordinary cylindrical combustion tube in a furnace capable of maintaining a temperature of 2350° F. may be used. Because the temperature must be maintained accurately, a platinum thermocouple, touching or near the outer surface of the combustion tube, and a deflection type indicator, are suggested.

Glass tubes passing through rubber stoppers, which are protected by nickel shields, serve as inlet and outlet to the combustion tube. A tube with a constricted end might be preferable.

The horizontal passage from the combustion tube, containing a stopcock, is bent vertically downward to enter the absorbing vessel, a 75-ml. tall bottle. Immersed to a depth of about 4 cm. in the absorbing solution, the end of the vertical tube is fashioned to break the gas stream into fine bubbles. It has been found that most accurate results are obtained when the passage from combustion tube to the bubbler is of the shortest length.

Oxygen for combustion is purified by bubbling through concentrated sulphuric acid. Rate of flow must be capable of accurate control and measurement in the range of one liter per min.

Reagents Used

Standard Sodium Hydroxide Solution: To 20 ml. of water add 0.500 grams of C.P. sodium hydroxide and 0.03 grams of methyl red. Dissolve, and make up to one liter. This solution should be standardized against a standard acid which has been prepared and standardized in accordance with well-known methods.

Silver Nitrate Solution: Dissolve 2.0 grams silver nitrate in water and make up to one liter.

Procedure: Weigh a 0.500-gram sample of white cast iron, finely crushed, and place in a refractory boat. Cover with a shield and place in the hottest part of the combustion tube, which should be between 2300° F. and 2400° F. Close the tube and, after allowing a one-min. warm-up period, turn on the oxygen at a rate of one liter per min., at the same time opening the stopcock to the absorbing vessel.

Five min. after the oxygen is turned on, slow the stream of oxygen somewhat, and titrate to neutrality with the standard sodium hydroxide solution.

If the standard solution contains 0.500 grams of sodium hydroxide per liter, the number of milliliters of this solution multiplied by 0.04 gives the percentage of sulphur in the sample.

Standard deviation in 34 determinations was 0.0018 per cent sulphur.

*Originally from a paper of The Iron and Steel Institute, London, November, 1943, by the Blast Furnace Analysis Sub-Committee of the Blast-Furnace Committee.

Sponsored by the Committee on Chemical Analysis of A.F.A.

If the oxygen is passed through the tube for 10 min. instead of 5 min., the results are sometimes 0.002 per cent higher.

Routine Precautions

When a new combustion tube or new bubbler is introduced into the apparatus, a check should be made, by running a standard cast iron sample. If correct results are not obtained on the first sample, the second sample usually gives the correct result and indicates that the apparatus is ready for the determination in hand.

A very common and important cause of erratic results is increasing the rate of oxygen flow appreciably beyond the one liter per min. This will give low results due to alkalies from the combustion of the cast iron being blown over into the absorbing solution and reacting with the HNO_3 in the solution.

Low results will also be obtained if the apparatus is blown out with oxygen previous to a determination at a rate appreciably higher than one liter per min., possibly due to alkalies from the combustion tube from previous determinations being blown over and accumulating in the lower part of the bubbler.

Effect of an oxygen flow slower than one liter per min. has not been investigated thoroughly, although it has been noted that low results are obtained if the flow is cut roughly in half.

Any dampness in the part of the bubbler or its connections above the part which enters the absorbing solution naturally will cause low results due to absorption of SO_2 before it gets to the absorbing solution.

New boats should be ignited under operating conditions before they are used; used boats should be treated similarly if they have been allowed to stand more than 8 hr. Although they can be used four or five times, it is better not to use a boat more than three times.

Combustion tubes have been used for about 300 determinations, without cleaning and without noting any change in results.

Table 1

Determination of Sulphur in White Iron

Sulphur, per cent			
0.142	0.146	0.140	0.138
0.146	0.144	0.142	0.143
0.144	0.142	0.141	0.141
0.144	0.144	0.141	0.144
0.142	0.142	0.140	0.143
0.141	0.143	0.142	0.144
0.143	**	0.142	0.141
0.140	0.140	0.141	0.140
0.143	0.140	0.140	
*	*	*	

Average of 34 determinations, 0.1420 per cent sulphur.

Standard deviation, 0.0018 per cent sulphur.

*Ignited Boats.
**Determination discarded due to bad bubbler.

Typical Results

A test run using the silver nitrate method on a standard sample of white iron is shown in Table 1. Tabulated are the results of successive determinations made during a period of 7 hr. total time. Thus 34 successful determinations, plus one which was discarded, were made at an average rate of one analysis every 12 min.

Advantages. The titration end point of this method is easy to see, and is not affected by carbonates. Although averaging slightly under those obtained by gravimetric methods, the results are based on theoretical chemical equations, and require no empirical correction factors or standardization against standard samples. The method gives correct results on National Bureau of Standards samples and the accuracy of the method described is confirmed by using the barium sulphate method.

Requiring no attention until titration, after the oxygen is turned on, time is saved by weighing the sample for the next determination. The results of titration of the absorbing solution depend upon the acidity of the solution rather than the oxidation of sulphurous acid to sulphuric acid, thereby eliminating any error due to sulphur trioxide coming over with the sulphur dioxide.

MALLEABLE SAND CONTROL in a Large Mechanized Foundry

By Joseph J. Clark, Assistant Metallurgist,
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USE of synthetic sand has become widespread with the advent of the high production foundry. The economic aspects and the control features have made it virtually a necessity in this type of shop.

Certain foundries employ two synthetic sands, one for facing and one for backing purposes. The backing sand is ordinarily supplied by suitable conveyor to hoppers over the molding stations, while the small quantities of facing are supplied by wheelbarrow to a box at the station, or by separate conveyor and hoppers.

While the requirements of some castings are such that two sands are needed, it is obviously highly advantageous, from a production and cost standpoint, to use a single, or 100 per cent facing sand. When using one all-purpose sand, it is equally obvious that more extensive conditioning equipment and more rigid control of both the molding sand and cores are required. As to raw materials involved, it is necessary that dependable sources be established for obtaining uniform raw sand, clay, seacoal, flour, core oil.

It is the purpose of this paper to describe the raw materials, equipment and controls employed in the synthetic, all-facing sand systems of a modern, high production malleable iron foundry, producing medium finish automotive and gun part castings, the weights ranging from a few ounces to 65 lb.

Raw Material Storage

Figure 1 shows the layout of the raw material storage building, containing bins for raw and prepared sand, clay and coal. A 5-ton traveling crane spans the building and railway siding to permit transfer of these materials by clam bucket. One portion of the storage building, directly below the small storage hoppers, is devoted to core sand mixing and seacoal preparation.

Attached to the main storage building is a sheet metal structure which houses the two sand driers and provides storage space for bagged materials such as flour, red iron oxide, clay, etc., used in core mixtures. Next to the drier building are the core oil storage tanks from which core oil is pumped to the core sand mixing room as it is used. All coal, clay, flour and core oil are purchased in carload lots.

The sand used in cores, and which ultimately becomes foundry molding sand, is a bank sand obtained from pits within a few miles of the foundry. It is hauled to the plant daily by truck and dumped into a concrete pit in one end of the sand storage building. From here it is transferred either to the wet sand storage bin or directly to the wet sand hoppers which feed the sand driers. The major portion of the sand stored for use is dried sand.

Sand Drying. Raw sand from the pits varies in moisture content from 3 to 9 per cent. It is the purpose of the sand driers to reduce this moisture to a very low and constant level (0.2 per cent approximately) so that moisture control of core sand mixtures can be maintained.

Each of the two parallel-counterflow type driers is capable of drying and cooling 8 tons of sand per hour. This figure is based on 7 per cent moisture in the incoming sand. A diagram of one of the driers is shown in Fig. 2. Due to the design, the driers are very efficient. A firebox located at the front end of the drier supplies heat to the air which is blown through and around it into the heating tube, as indicated by the arrows.

The firebox is fired with natural gas and is automatically maintained at 1400° F. Wet sand is fed into the rotating drum between the outer shell and the heating tube. Blades attached to the inside surface of the outer drum, alternately raise and drop the sand as it works toward the midsection of the drum, thus exposing it to the heated stream of air.

The path of the air stream is such that the temperature of moisture laden gases leaving the stack in the heating section is less than 212° F. At the midpoint of the drier, the moisture in the sand has been reduced to about 1.5 per cent. The sand enters the cooling section of the drier through special inclined feed scoops, which also act as a baffle between the heating and cooling sections.

As the sand enters the cooling section, it falls on a fixed thermocouple. The temperature of the sand at this point is used to control the final exit temperature of the sand and subsequent moisture con-

• This paper on malleable foundry sand control is one of several being prepared at the request of the Malleable Division Program Committee, which is planning to continue the yearly symposia on malleable foundry practice started several years ago. These papers on this subject will later be incorporated in a reprint on malleable sand control as the Division's contribution to the 1945 program. Included in this symposium will be the summary of some 14 companies' answers to a questionnaire on malleable sand control.

The ultimate objective of the Division is to later incorporate all of these symposia in a book on malleable foundry practice. Previous symposia covered (1) Graphitization of White Cast Iron, (2) Malleable Iron Melting, and (3) Gating and Heading.

tent. This is accomplished by a pyrometer-controlled damper on the fan supplying air to the heating section of the drier.

Decreasing sand temperature automatically increases the amount of hot air blown through the heating section, and vice versa. A constant volume of air is blown through the inner cooling tube by a separate fan. The velocity of the cooling air is such that considerable "pan" material or fines are removed from the sand and are carried out the exhaust into a dust collector.

The sand is discharged from the cooler at temperatures between 95° and 110° F. into an elevator, which in turn drops it onto a 20-mesh vibrating screen inclined at a 33° angle. Extraneous materials, coarse sand, roots, etc., pass over the screen and are collected in a tailings hopper. The dried sand passing through the screens is carried by conveyor belt to the dry sand storage bins.

Seacoal Preparation. Seacoal for use in the sand units is prepared by crushing coal purchased exclusively for this purpose. The seacoal crusher is one of the latest types, employing the ball bearing grinding principle with spring loading of the grinding elements. It operates at relatively low speeds. The unit will supply 3000 lb. of seacoal per hour.

Core Sand Preparation. The core sand mixing and handling equipment is shown diagrammatically in Fig. 3. The mixers are of the kneading type, having Sigma-shaped blades. Standard batches mixed in them are made up for either 1800 lb. or 1050 lb. of sand.

All dry ingredients are weighed, and all wet ingredients are measured by volume. Dried sand from any one of several overhead hoppers may be discharged into a weigh lorry by means of electric vibrating feeders. The feeder is automatically stopped by an electric eye device on the scale when the batch weight of sand is in the lorry. The lorry may then be moved along the overhead rail and the sand discharged through a butterfly valve into any one of the mixers.

Corn flour, which has been weighed, is added to the mixer as the dry sand is flowing into it. Any other dry ingredients such as red oxide, clay, etc., also are added to this time. These are dry mixed for one min., followed by addition of the water and core oil in that order.

The batch is wet mixed for 7 min., making a total mixing time of 8 min. A time clock is used to notify the operator when mixing time is up. The prepared sand is then discharged onto a conveyor belt below floor level, and from here it is elevated and discharged into one of a cluster of hoppers conveniently arranged in the core room.

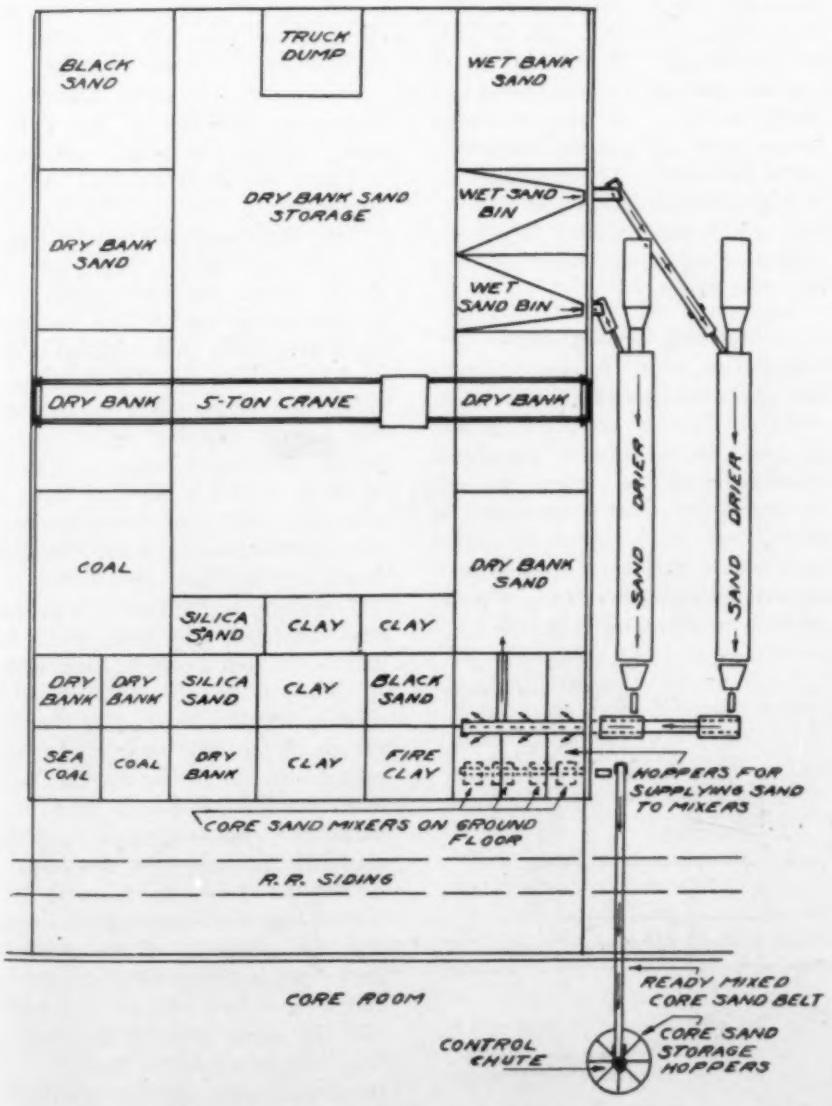


Fig. 1—Layout of sand storage and preparation units.

Core Mixture Control

Since there are a number of different core mixtures in use at all times, it is important that each type goes into the proper hopper. This has been cared for by means of an electrically controlled receiving chute (Fig. 1) above the cluster of storage hoppers which are arranged in a circle in the core room. By means of push buttons and signal lights, the operator in the mixing room may revolve the chute about its axis to a position over the proper hopper and then proceed to dump the mixer.

Foundry Molding Sand Handling and Conditioning Units. Four individual sand units are used, each one equipped to completely handle and condition its own sand. Every unit must furnish a continuous supply of sand to the various molding stations of the production lines composing the system. There are no batch type operations in any of the systems.

The number of molding stations supplied by a sand unit varies from 10 to 34, depending upon the type and size of molds made on the lines. Since different standards of moisture, permeability, etc., are maintained on each system, the placement

of patterns in the most suitable unit is possible. Figure 4 shows a schematic diagram of one of the units.

Prepared sand is plowed off the overhead, or "flight" belt conveyor into the individual sand hoppers located above each molding machine. The quantity of sand sent out on the belt and the adjustment of the various plows is gauged by an operator who patrols this section of the sand system.

An improvement in discharge of sand from the molder's hopper to the flask has been made by installing an electric vibrating feeder on each hopper, instead of the usual manually operated jaws. Much better control of the amount of sand for each flash is obtained, thus reducing the spillage of prepared sand. Labor expended in operating the jaws is eliminated.

Automatic Equipment

An automatic jolt-squeeze equipment is provided for each molding machine. The operator's controls consist of a "jolt" push button, a "squeeze" push button, and a "stop" button. The jolt button engages a timer which gives the mold a predetermined number of jolts, whereas the squeeze button actuates controls governing the intensity and duration of the squeeze and, in addition, it controls the slow draw of the pattern from the mold.

Any excess or "spill" sand from the mold falls through the floor grating which surrounds each molding machine and drops onto a spill-sand conveyor belt in the pit below. Excess sand from the end of the overhead flight conveyor also drops onto this belt through a tail chute. Spill sand collected in this manner is returned to the spill sand storage bin after passing over a magnetic pulley and through a vibrating screen.

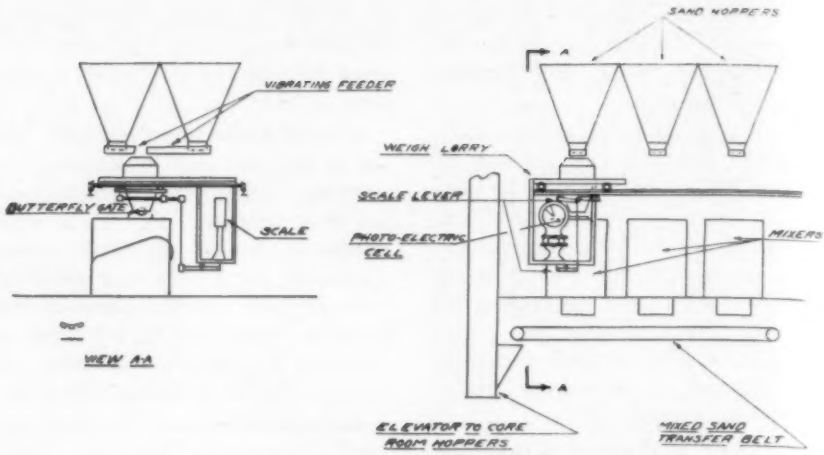


Fig. 3—Views of core sand weighing and mixing equipment.

Completed molds are placed on a conveyor which carries them past the pouring conveyor, where they are poured off. The poured molds continue through a cooling hood and finally reach a vibrating shakeout screen, where the castings are shaken out of the molds. The shakeouts are of rugged construction and the motion is sufficiently violent to remove all but a very small amount of sand from the castings.

Handling Shakeout Sand

Shakeout sand passing through the shakeout screen falls into an electric vibrating conveyor in the pit, and is fed into a horizontal cylindrical cooling drum. As the cooling drum rotates, the sand is picked up by a series of blades attached to the inner wall. Air is drawn through the drum, cooling and drying the sand as it falls from the blades. The velocity of the air is such that a considerable amount of fines is removed from the sand.

From the cooling drum, the shakeout sand passes over a magnetic pulley, is screened to remove core butts, lumps, etc., and falls into the shakeout sand storage bin.

Floor hoppers with controlled feeders are provided so that, if desired, sand may be added uniformly to either the shakeout sand or the spill sand.

The shakeout sand storage bin, the spill sand storage bin, and the seacoal bin are located in a row for convenience in feeding the continuous muller. The shakeout and spill-sand bins are equipped with electric vibrating feeders, while the seacoal bin has a variable speed screw feeder. Controlled amounts of each of these materials are fed onto a cross-belt which spills into the entrance of the muller, where clay and water in slurry form are added.

The slurry is prepared in a special tank overhead, and feeds down by gravity through a pipe to the muller. A simple plug type hand valve is used to regulate the rate of flow of the slurry to the muller. In the preparation of the slurry, clay and water are fed into a tank where two propeller type agitators rapidly establish and maintain the suspension of the clay in the water.

The size and shape of the tank and the positioning of the agitators are of prime importance in making an effective slurry. In order to maintain the slurry level in the tank, a float switch is used to stop or start the flow of water and clay simultaneously. In the case of the water, the

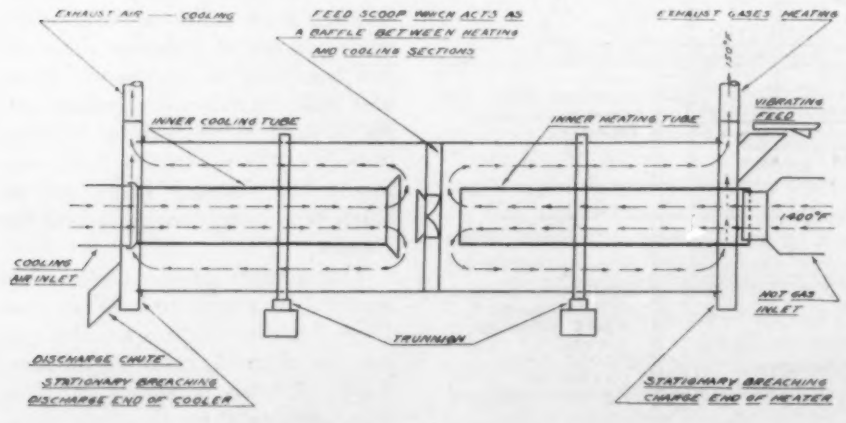
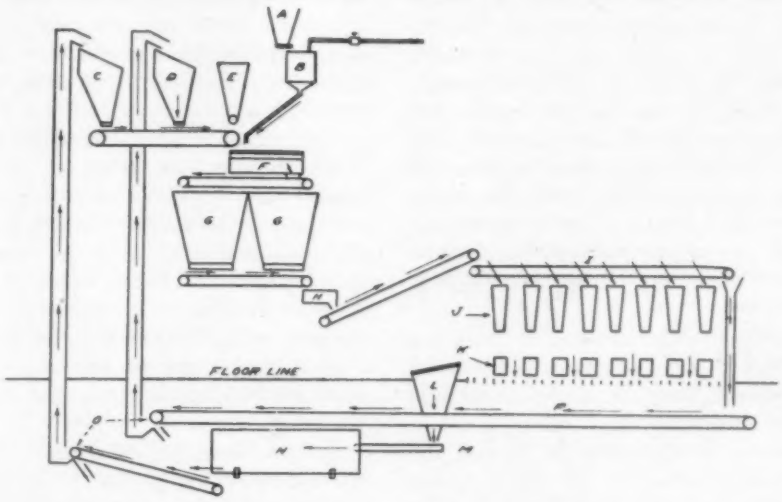


Fig. 2—Diagram of combination parallel and counterflow sand dryer and cooler.



A. Clay hopper
B. Slurry preparation tank
C. Shakeout sand bin
D. Spill sand bin
E. Seacoal bin
F. Continuous muller
G. Tempering bin
H. Revivifier
I. Flight belt
J. Molder's hoppers
K. Molding machines
L. Shakeout
M. Vibrating conveyor
N. Cooling drum
O. Magnetic pulleys
P. Spill sand return belt

Fig. 4—Schematic diagram of foundry molding sand handling and conditioning unit.

float switch operates an on-off solenoid valve in the water line; in the case of the clay, it stops or starts the variable speed screw feeder, located at the base of the clay bin.

A pressure regulator controls the water-line pressure so that a uniform rate of discharge of water into the slurry tank is maintained during the time the solenoid valve is on. The rate of clay feed may be adjusted by changing the speed of the screw feeder.

The mixture of spill sand, shakeout sand, seacoal, and slurry enters the muller from the crossbelt and is mulled as it progresses to the opposite end, where it is discharged through an opening in the base. Figure 5 shows plans and sectional sketches of the muller which is equipped with Sigma-shaped blades attached in segment form to two horizontal shafts.

The shafts rotate in opposite directions and at different speeds, the blades working the sand inward against the "saddle." In order to mull effectively, the proper clearance between the blades and muller faces must be maintained. This is made possible by the use of renewable white iron shoes bolted to the blades. A 125-horsepower motor drives the muller.

The mulled sand drops onto a conveyor belt from which it may be plowed off into either of two 150-ton tempering bins. These bins are of sufficient size to permit sand to temper for at least one-half hour. For control purposes, sand is fed from one bin for 30 min., then from the other. Each bin is equipped at the bottom with an electric vibrating feeder which shakes a regulated amount of sand onto the cross belt below it.

As the sand leaves the tempering bin, it receives a final conditioning in a revivifier, where the action of a revolving "squirrel cage" aerates the sand as it passes through. From here it travels to the flight conveyor to service the molding stations. Approximately 175 tons of sand per hour are "turned over" on this unit. Total sand carried in the unit is about 250 tons.

Raw Material Control — Bank Sand. The raw sand is a sub-angular bank hand of approximately 70 A.F.A. grain size. It is important that no major deviations develop in the grain distribution. Consequently, a routine check of the grain distribution curve of incoming sand is made once per day by analysis of a composite sample taken at the belt feeding raw sand to the sand driers.

In making an analysis of the sand by means of distribution curves, extra sieves, other than standard, often furnish more detailed information. They are used regularly. Figure 6 shows bank sand curves plotted with standard sieves, and with the additional sieves.

The control of the exit temperature (95 to 110° F.) of the sand from the driers is of utmost importance. Hot sand is to be avoided for two good reasons:

1. Loss of moisture control of core sand mixtures due to evaporation.

2. Hot sand in core mixtures causes sand to stick in core boxes.

Sand under 95° F. at the drier discharge is also to be avoided because it will be too wet.

In addition to drying the sand, two other controls of bank sand incorporated in the driers and auxiliary equipment are:

1. Removal of fines in the cooler section of the driers.

2. Removal of very coarse sand and extraneous material on the vibrating screens.

Screen analysis of the tailings is used as a check on the efficiency of the screening operation.

From time to time new pits must be opened. At such time, the sand supervisor goes to the pit to observe the general conditions and sampling procedure to assure himself that samples to be tested are representa-

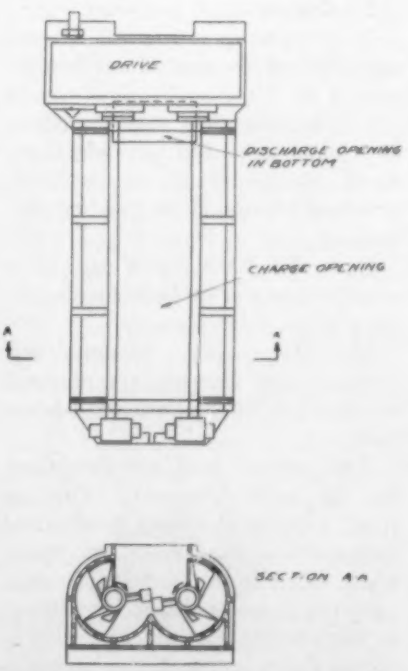


Fig. 5—Plan and sectional sketches of continuous sand muller.

tive of the average sand to be taken from the pit.

Clay. The clay used is an unpulverized (30 mesh) rebonding type clay of high refractoriness and good durability. A check on the latter quality is always available through accurate records of the tons of metal poured versus clay consumption on the sand units. Incoming cars of clay are checked for green and dry bond according to A.F.A. standard procedure.

Seacoal. Coal for manufacturing seacoal is of a West Virginia variety, purchased under the classification of 1¼-in. nut, pea, and slack. Cars are sampled as received, and laboratory tests are made for ash, volatile combustible matter, and fixed carbon. A minimum of 30 per cent volatile combustible matter, and a maximum of 6 per cent ash are specified.

The seacoal is crushed to a fineness such that 99 per cent will pass through 100-mesh and 85 per cent through 200-mesh screens. Periodic screen analyses are made to insure that the foregoing specification is maintained because experience on the sand systems has shown that many detrimental effects result from the use of too coarse a seacoal. These may be enumerated as:

1. Blows become much more prevalent in castings, particularly the smaller ones.
2. Casting finish is poorer.
3. Greater quantities of seacoal are required because of ineffectiveness of it.
4. The molding sand accumulates more coke and ash, which reduces tensile strength of the sand, ultimately resulting in molding difficulties.

Core Oil. Each car of core oil is subjected to test by both the chemical and sand laboratories.

Specific gravity, saponification number, and viscosity are reported on each car by the chemical laboratory.

Two sets of tests are conducted by the sand laboratory. One of these consists of baked tensile and permeability tests made on specimens taken from a laboratory mixture, using standard sand, and baked in the laboratory oven. The other is identical, except that the baking is done in production ovens.

A particular core oil may show excellent properties in a core baked in the laboratory oven for 1½ hr. at 420° F.; however, it is often the case that, due to the inherent characteristics of the oil, the same core may show much poorer when it is subjected to the baking cycles used on the production ovens. The latter test often classes an oil as unsuitable for use in the core room without making major changes in coreroom practice.

Flour. New batches of flour are checked for green compression strength, using an emperical mixture with standard sand. Since a major portion of the cores are blown, the characteristics of the flour which effect its "blowability" for intricate core sections are under as close observation as are other properties. To aid in the selection of flours with suitable blowing properties, and as a routine check on incoming shipments, the weight per cu. ft. is determined according to an arbitrary standard.

This check is made by sifting the flour through an ordinary sifter placed on a fixed funnel which sets on a quart measure. The funnel diameter is almost as large as the quart measure. When the quart measure is filled to overflowing, the excess is scraped off with a straight edge. The weight of the quart of flour is obtained in grams and converted to lb. per cu. ft.

It has been the experience that the lighter flours (10 to 13 lb. per cu. ft.) "blow" much better than the heavier flours (14 to 20 lb. per cu. ft.). On this basis a maximum of 13 lb. per cu. ft. has been set up

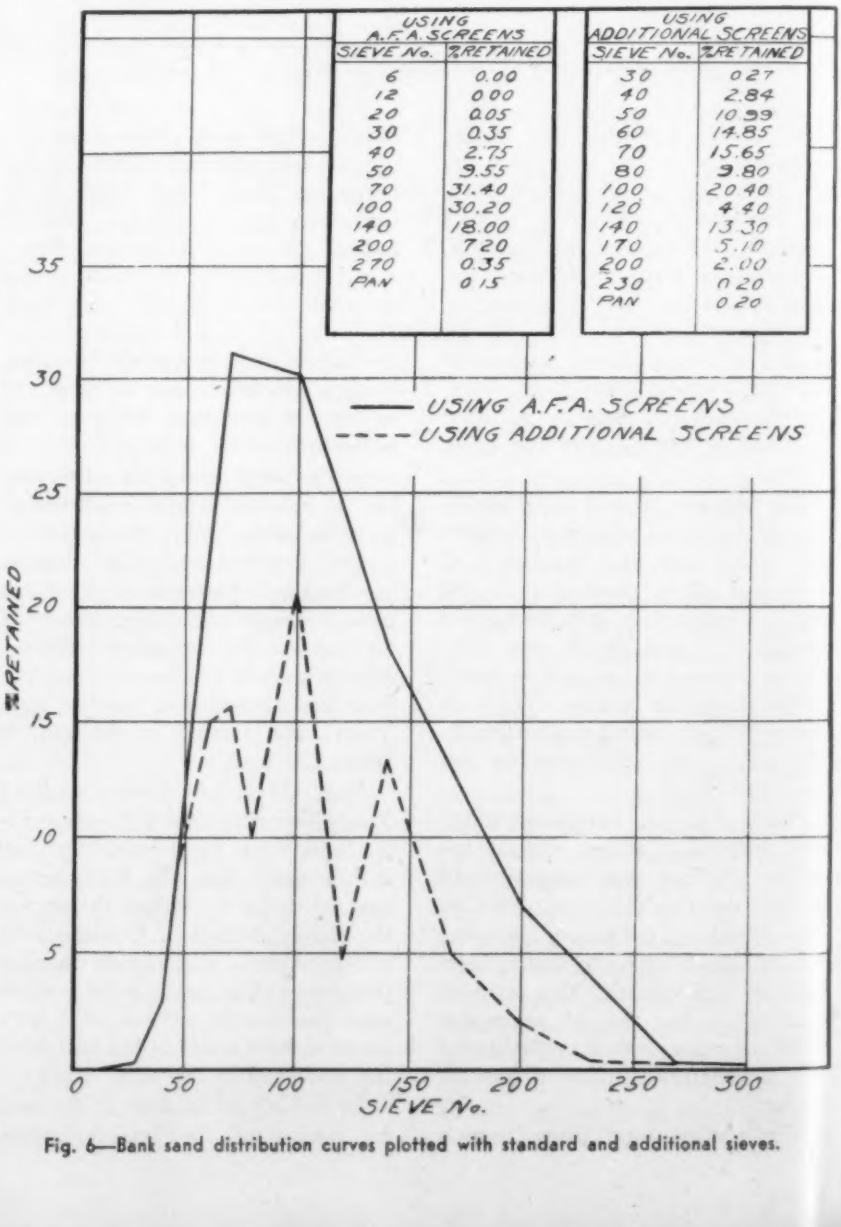


Fig. 6—Bank sand distribution curves plotted with standard and additional sieves.

as an arbitrary figure for the density of flour.

The variations in flour from shipment to shipment can cause no end of trouble in the coreroom if precautions are not taken in segregating the shipments. Moreover, if flour stands for long periods of time, the green bond developed by it is lower. A system has therefore been established wherein the oldest flour is used first; incoming batches are piled in rotation. Flour adjustments in the core mixtures may then be made as needed and consistent results obtained.

Core Sand Control. In a synthetic sand system, sand additions to the system should come entirely from the cores. Consequently, the core practice with respect to ingredients and properties is of utmost importance in shops using synthetic sand.

Two-Sand System

Shops using a two-sand system in the foundry, i.e., backing sand and facing sand, can and do solve many of their core problems by using any one of several sands in the cores to obtain desired properties. This is permissible on the basis of the fact that the sand from the core eventually goes into backing sand and, as such, has little effect on casting finish.

Where a single, or 100 per cent, facing sand is used in the foundry, however, limitations are automatically imposed on the core sand selection due to the effects on the molding sand and ultimate effect on the castings. Therefore, large quantities of miscellaneous sands having widely different grain fineness and distribution cannot be used in the coreroom in this shop. More than 99 per cent of all the cores are made from the local bank sand.

The primary consideration in developing a core sand mixture is that of making a core which will result in the production of consistently good castings in the foundry. However, any core which fails to collapse properly and disintegrate at the mold shakeout represents a loss of good sand to the system. If there are many cores of such nature being used, the sand normally lost through adherence to the castings is not entirely replaced with core sand and the volume of molding sand in the unit is reduced.

In order to maintain the volume of sand required to operate the unit successfully, it then becomes necessary to feed new raw sand into the system, increasing labor and materials cost and upsetting control of the molding sand. Core mixtures are consequently developed not only to produce good castings, but also to produce desirable and economical conditions on the molding sand systems.

Standard Mixtures Developed

A number of standard core sand mixtures have been developed to take care of the major core production requirements. For these mixtures, standards have been set up for moisture, green compressive strength, and baked tensile strength. On each shift, samples of sand from each type of batch made are tested for these three properties.

The baked tensile tests are made on briquettes baked in the standard laboratory oven. As a check on production baking, briquettes are frequently put through the production ovens. Minor adjustments of the various ingredients to maintain the accepted standards are made by the sand control laboratory on the basis of the routine tests.

No matter how well core mixtures are made and controlled, the potential benefits are washed away if the sand handling practice, coremaking and baking equipment are improperly controlled.

Many core troubles in the foundry which are ascribed to the properties of a core mixture can often be traced to soft blowing or ramming, faulty venting, incomplete baking, overbaking, etc.

Molding Sand Control

General Control Aspects of the Molding Sand Equipment—Automatic Jolt-Squeeze Molding Machines. When automatic jolt-squeeze equipments are used, much of the "human element" can be eliminated in making a mold because the number of jolts and extent of the squeeze can be standardized to suit the job, and are thus taken out of the operator's hands. With such equipment, and very close control of molding sand properties, high mold production with a minimum of scrap can be attained.

On the other hand, unless care is exercised in making and maintaining a good "set-up" as far as machine, flasks, squeeze heads, etc., are concerned, it is possible to make a lot of scrap in a short time, even though good sand is supplied. Scrap can also be made by an operator who fails to observe the simple rules of the job, such as completely filling the flask with sand and striking it off before squeezing.

Shakeout Sand Cooling Drum. The shakeout sand cooling drum, through its functions of cooling and drying the shakeout sand, permits much better control of the molding sand. When the temperature of molding sand can be kept down, its moisture content can be more closely regulated because evaporation is minimized. Hot molding sand tends to stick to the patterns due to the formation of condensate. This tendency is eliminated with cool sand.

Sand Drying

The drying of the shakeout sand in the cooling drum has an indirect, but marked, influence on casting finish because it permits more efficient screening of this sand than would be possible with wetter sand. The drier the sand, the smaller the screen openings that can be used without fear of "blinding" them, and the greater the proportion of core butts and lumps that can be screened out.

The removal of "fines" which are picked up by the air stream in the cooler is very desirable from the standpoint of maintaining permeability and reducing seacoal ash, dead clay, etc., in the system.

By reducing the moisture of the shakeout sand, more water can be added when re-mulling the sand. This is an advantage when clay is being added in slurry form because it permits a thinner, easier flowing slurry to be used.

Separate Shakeout Sand and Spill Sand Bins and Screens. As previously mentioned, dry sand can be screened more effectively than wet sand. Shakeout sand is relatively dry as compared to spill sand. It also contains core butts, lumps, etc., in large quantities, whereas spill sand is relatively free of them. If these two sands were dumped in together, effective screening would be impossible. With the separate screens and bins, a fine screen can be used for shakeout sand and a coarse screen for spill sand to maintain a

molding sand of facing quality.

Reconditioning Methods

For reconditioning shakeout sand, clay, seacoal, and a large quantity of water are required. For reconditioning spill sand, only a small amount of water is required. It is obvious that if these two sands were allowed to mix in varying proportions as they returned from the molding line (that is, collected in one bin) the problem of adjustment of clay, water, and seacoal to obtain uniform sand from the muller would be extremely difficult. By providing separate bins, the feeding of each type of sand to the muller may be closely controlled and additions made in accordance.

Clay Slurry Equipment. The primary purpose of mulling a sand is to coat the sand grains with a film of clay. When clay is added in slurry form the sand grains are quickly and thoroughly coated with clay since the water acts as a carrying agent. Therefore, a minimum of mulling is required to develop bond. This feature is of exceptional value where large volumes of sand are being conditioned continuously and mulling time is limited.

When using clay slurry for rebonding, less clay is used in the system because ineffective clay and clay balls are kept to a minimum. Aside from the savings in material and labor, the reduction in amount of clay used has favorable effects on the sand properties:

1. Permits use of lower moisture standard for temper at desired green bond.
2. Increases permeability.
3. Increases flowability—an important factor in jolt-squeeze molding.

The rapid response of the sand to clay additions in slurry form enables a more positive control of green and dry bond to be exercised. This feature is in sharp contrast to the slow action of clay added in the form of a dry rebonding mix (sand and clay) where mulling is the principal means of making the clay effective. "Overshooting" or "undershooting" bonding additions is much more prevalent when dry rebond is used.

Continuous Type Muller. Although it is possible to "match mull" sand for a continuous molding unit, where very large quantities are to be handled several such mullers and considerable labor are required. The continuous type muller has been found to fit into this foundry's systems much better, involving relatively little space and minimum labor. Mulling action can be roughly checked by means of the load ammeter on the drive motor. Other factors remaining constant, the extent of mulling (work) is proportional to the load ammeter reading.

Mixing Control

From a control standpoint, it is vitally important that the muller shoes be renewed and properly set at regular intervals, otherwise the system builds up ineffective clay while the green bond is actually falling. As previously mentioned, this action is particularly acute if dry rebond mixture is used to add clay to the systems.

Tempering Bins. Instead of storing large quantities of shakeout sand ahead of the muller, as is common practice, in these systems the sand is stored in two large tempering bins after mulling. By feeding alternately from the bins a degree of moisture equalization and tempering is obtained. With ample storage capacity, "turnover" of the sand is slow and molding sand temperatures can be kept down.

Revivifier. The sand discharged from a tempering bin is usually packed and chunky. The revivifier serves to aerate it thoroughly before it goes out to the molders. This treatment materially improves an important property of molding sand —flowability.

Routine Control of Molding Sand —Routine Tests. Standards for moisture, permeability, and green compressive strength to be maintained on each unit differ considerably due to the type of castings being made on the lines. Moisture standards range from 4.0 to 4.8 per cent, permeability from 40 to 60, and green compressive strength from 8 to 10 psi. Hourly tests for these three properties are made on sand samples from each of the four systems.

A dry compressive strength test and a green tensile strength test are made each shift.

System sand distribution curves are plotted and percentage of clay and seacoal are determined once a month.

Moisture Control

Water addition to the sand for desired moisture is made by means of the clay slurry. An indexed hand valve in the slurry line to the muller is used to regulate the flow of slurry.

Factors affecting moisture control are:

1. *Sand "turnover."* This term means total sand, both shakeout and spill, being mulled per hour. This is affected by the amount of shakeout sand and amount of spill sand returning. Increased tonnage requires more water.
2. *Relative amounts of shakeout and spill sand being mulled.* The relative amounts of these sands being mulled will alter water requirements as one sand is higher in moisture than the other.
3. *Temperature of sand.* The hotter the sand becomes, the more rapidly evaporation takes place and the more water is needed.

Temperature of the sand is influenced by the volume of sand carried in the system, bridging of the bins, rate of molding, and temperature inside the foundry.

4. *Types of jobs being poured on the lines.* The amount of water to be added is also influenced by the size and shape of the castings with respect to flask size, and by the relative amount of cores involved.

Bond Control

Clay addition to the sand is made in the form of slurry. To increase or decrease the clay addition, the speed of the screw feeder on the clay bin is adjusted to deliver more or less clay to the slurry preparation tank. The rate at which water is added to the tank is held constant, so the slurry consequently is increased or decreased in concentration.

Bond control of a system is affected by: (1) *Sand "turnover."* (2) *Relative amounts of shakeout and spill sand being mulled.* (3) *Types of jobs being poured on the lines.* Large additions of new sand to the system via cores require proportionately large clay additions for bonding and vice versa. (4) *Condition of muller blades.* Ineffective mulling will cause the bond of the sand to fall even though the proper percentage of clay is maintained in the system.

Permeability Control. The permeability of the sand can best be

controlled by close control of the many factors affecting it, among which are:

1. *Grain size and distribution of the sand.* As previously mentioned, this is governed primarily by choice of core sand.

2. *Amount of moisture, clay, and seacoal in the sand.* Increasing percentages of any of these in the sand cause decreased permeability.

3. *Percentage of miscellaneous fines.* Aside from the clay and seacoal, other fines such as dead clay, seacoal ash and coke, and dust from broken-down sand will lower the permeability of the molding sand.

4. *Temperature of sand.* Increasing sand temperature lowers the permeability of the sand.

Control—Seacoal

Seacoal additions are controlled by regulating the speed of the screw feeder on the seacoal bin.

Seacoal is used in the sand to reduce "burn-on" and improve casting finish. Aside from its low cost, it has few virtues and several disadvantages, among which are:

1. Reduces permeability of sand due to large amount needed (5 to 10 per cent).

2. Leaves ash and coke in the sand.

3. Difficult to control properly.

A satisfactory method of testing for effective seacoal content quickly and accurately has not been devised. For this reason, in routine control reliance is placed on a combination of experience, knowledge of jobs running in the unit, and visual inspection of castings as they come from the shakeout, as guides in regulating seacoal content.

Poor regulation of seacoal has serious effects not only upon the castings, but upon the volume of sand in the system and hence upon control of other additions. When excessive quantities of seacoal are used, misruns, blows, and cold shuts prevail in the castings. When insufficient seacoal is used, the sand burns onto the castings, resulting in increased cleaning costs and unsatisfactory finish.

Under the latter condition, the sand volume is lowered rapidly in the system due to increased amounts of sand adhering to the castings. Sand must be added to the unit at extra cost to offset this loss.

Sand Records. When large quantities of molding sand are being conditioned daily, as they are in this plant, accurate records of all materials and tests form an invaluable part of sand control. Such records, when correlated with tonnage of iron poured, percentage of scrap, etc., can give a clearer picture of sand performance and actually can be used as a guide to control.

In addition to offering a useful check on performance of raw materials, sand system records often assist in detecting unfavorable core or molding sand practices that otherwise escape the sand supervisor.

Conclusion

Much of this paper has been devoted to a description of equipment and tests designed to enable good molding sand and cores to be furnished to the foundry. Whether or not this goal is reached always depends upon the proper maintenance and operation of the equipment, and upon the close attention of foundry supervisors to the details of good practice which collectively constitute what is known as "control."

INSPECTION OF STEEL CASTINGS

C. F. Rohlkoetter

American Steel Foundries
East St. Louis, Ill.

● ***Adoption of many new technical tools has brought about remarkable advances in foundry practices and improvements in products. From cooperation with designing engineers to judging the quality and serviceability of the finished casting, well-organized inspection units have helped the foundryman to make better castings at lower cost.***

START OF INSPECTION, as is well known, was due to the fact that supervisors in charge of the progression of work had little time for quality. As a result, help was needed for inspection of the work to insure proper quality. The addition of inspection greatly relieved the supervisor in charge of production, enabling him to study ways and means of increasing production throughout the department.

Inspection work in its infancy was taken with a feeling of resentment and was considered a "necessary evil." An inspector's job in the early days was no bed of roses; he was between two fires at all times, namely, the antagonistic attitude of the worker who believed he was being hindered in his work, and resentment by supervisors who felt that the inspector, in trying to produce a quality casting, was responsible for hindering production. Thus, when the sequence of operations did not function freely, the inspector sometimes was blamed for this delay in production.

As the years went on, the supervisor was convinced that inspection was here to stay. He realized that it was necessary to have inspection, not only to insure the proper quality of production, but also to aid in the sequence of operations. As a result of inspection, top management's attention was drawn to the fact that complaints of the customers were reduced greatly due to the improved quality of castings shipped, and naturally this improved quality increased sales. Thus inspection was set up in industry as routine function of production and not, as previously considered, a "necessary evil."

As inspection progressed, it was found that inspection solely on the finished product was not sufficient and it was essential that inspection extend into actual production. This type of inspection was termed process inspection. Today we are placing more and more emphasis upon inspection of core and molding procedures. This inspection insures use of proper sand and proper solidifyplacing of vents. It also insures proper fit of cores in the mold, and thus helps to insure proper dimensions of finished castings.

Customer Trained Inspectors

The customer early came to realize that he needed some way to insure the quality he desired, so he began training inspectors of his own and sending them into the producers' plants to make certain he was getting the quality he desired.

It is always best to accept outside inspection openly, remembering that if the local plant inspection forces are properly trained and the product is up to customer's standards, additional inspection from an outsider ing methods, correct ramming and helps to increase confidence in the product.

In the past, the author believes, outside inspection was looked upon with a certain amount of resentment by some of the producers. However, present-day management welcomes inspection from the customers. It helps to keep the plant organization alive, and on their toes, but, regardless of outside inspection, all products shipped should be up to standard quality.

Inspection in industry at this time is well organized or should be, working closely with the designing engineer's department as to welding limits, defects, tolerances, and customer's requirements or specifications. This cooperation is necessary since it helps the production department in a number of ways, such as changing intricate designs that cause trouble in the production of quality castings.

The inspection department also should keep production departments advised at all times, and as soon as possible, as to points of inherent defects, so that prompt corrective measures may be taken to insure a low defect rate. The pattern department should be notified as to faulty dimensions in order to correct these errors at once.

A review of the product in process, to eliminate defective castings as soon in the sequence of operations as possible, is essential to prevent high production costs. Repairing of minor defects should be controlled by well-trained shop inspectors, but all defects of major size need the judgment of a supervisor with training of both practical and technical nature.

First, he should understand the direct use of the castings in question; second, to know high stress points and intermediate stress points, along with a well balanced practical knowl-

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edge, which will help to produce quality castings.

A sequence of shop inspection may be as follows: Checking or laying out castings to blue prints before full production is started. If no changes are to be made to pattern or core box equipment, first run of several castings should be made and all gages, which have been designed for casting after being carefully checked to drawing, should be applied to casting to determine whether casting will meet customer's requirements.

Inspection of regular run castings should then begin, after castings are received from the foundry in the as-cast state, checking the castings for defects and various outside and inside dimensions as to maximum and minimum tolerances. Many headaches may be avoided at this point if inspection and production department heads cooperate properly. Inspection then should continue through the finishing operations; gages and templates which were used on first run castings should be applied and properly fitted.

The finish of the castings also should be considered. Additional inspection then should be given castings by final inspectors, and all points of castings should be rechecked for defects. The work of inspection should be done so thoroughly that, whether or not customer's inspection is required, a quality casting is shipped at all times. However, if customer's inspection is not required, an additional company inspection should be made by the inspection department supervisor or his appointed representative for a final check before shipping.

It is the author's opinion that a well organized inspection unit should be formed, consisting of three parts. First, a well organized process inspection department should function in the coreroom and foundry, working in accord with the heads of both departments, with full power to suggest and help correct all faulty conditions existing in these departments pertaining to quality castings.

Second, a technical unit for x-ray and magnetic particle inspection of all samples and experimental castings to insure sound castings. Internal defects can be pointed out to the foundry and corrected at once.

Third, a practical unit consisting of well trained sample checkers and inspectors adapted to all inspection problems. These men should be capable of passing judgment as to what is a good quality and serviceable casting, in compliance with the plant and customer standards.

It also is necessary to plan all production. A committee should be formed of the supervisors of all departments controlling production. This committee should review and plan all production before even a sample is produced. It is advisable to review future or proposed orders on production, making sure that the designs of castings reviewed will fit into the plant's production system and equipment.

Production Begins

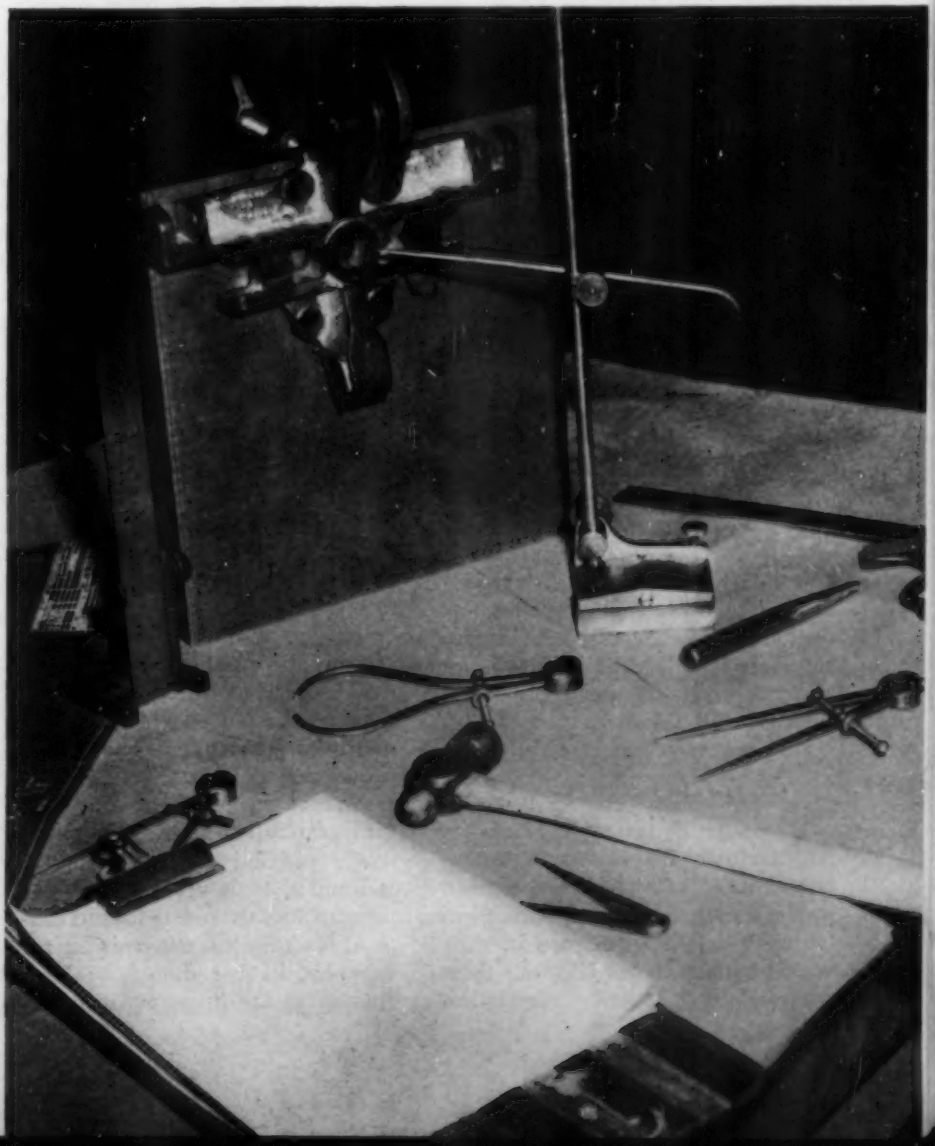
After a sample is made and reports from the technical and practical units are received, the planning committee should review these reports and make the necessary corrections if needed. The job then should be put into production for a trial run, making several castings which are to be checked in the same manner as the sample. If these are proven correct, full production can be released without the danger of any great loss, extra work, or cost for the cleaning room.

Inspection at the source having been discussed, some consideration should be given to inspection at the receiving point, meaning the customer.

As previously brought out, cost is increased when efficient inspection is lacking at the source of production; therefore, it is imperative to maintain a highly trained inspection personnel. This same principle applies to the customer's inspection. Cast steel is greatly used due to its adaptability to intricate designs and strength required. Of course, slight imperfections may occur, so, unless the customer's inspection personnel has the proper training and techni-

Inspection layout for checking dimensional accuracy of castings.

(Courtesy Caterpillar Tractor Co.)



cal knowledge to pass upon minor defects and those of a more serious nature, considerable cost is involved, both to the customer and the producer.

In cases where intricate designs would cause trouble from a production standpoint, the customer should be contacted and advised why and where a few changes in design can be made without impairing the service or strength of the casting; or changing any machining operations should the casting be of such nature. These suggestions usually are agreeable to the customer and permission generally is granted to proceed with production.

Inspection Is Technical

As we all know, present inspection consists not only of surface inspection, gaging, checking of dimensions, etc., as in the past, but is rapidly becoming more and more of a technical nature. The use of magnetic particle testing, x-ray and various other specialized tests shows a decided change in inspection methods over the past few years and in prospect for the immediate future.

In the past decade or two, inspection procedures have expanded greatly to include many new phases that are the result of developments in technical researches. The foundry industry was at first a trifle slow in adopting and applying some of the developments, but of late years the industry as a whole has thrown off this backward attitude and the advances and improvements in processes and products have been phenomenal.

What has brought about this change in our industry? It is largely the result of widespread adoption and use of many new technical tools. For the most part, these new tools had been previously developed to a fairly high level of perfection, yet these tools usually were considered as laboratory playthings and not as production tools, referring to such things as x-ray, magnetic particle testing, and others.

Inspection Methods Familiar

Most foundrymen were somewhat familiar with these inspection methods, that is, they had heard or read of their uses, but very few of them had any actual experience in their use and many had never seen them was obvious that the foundry industry must step out and do things that normally it would not have thought in operation. Early in the war it possible. The demands of the armed services made it imperative that the industry accept these new laboratory tools and use them as means for development and improvements toward high quality castings.

Let us consider some of these new tools in more detail and see what their effect has been upon inspection procedures and upon quality of inspection. When we think of casting quality from the standpoint of soundness and freedom from internal defects, probably the most helpful tool for this purpose has been the use of radiography either by x-ray or radium.

Previously, the only way to determine the soundness of a casting was to destroy it—by cutting the casting into pieces to see what was inside it. This process was necessarily slow and costly and somewhat of a hit-or-miss proposition, for often the saw cut would not reveal the defect.

X-ray and Radium

X-ray and radium have been available to the foundry industry in a more or less limited way as an inspection tool since early in the 1920's. At first we were somewhat skeptical of its use in routine inspection processes; and today, after several years' experience, we still are not convinced that inspection of castings by x-ray is desirable or even justified, except in certain extreme cases. For instance, in aircraft construction, a casting failure might be the cause of a disaster, then 100 per cent radiographic inspection would be justified.

Radiography certainly has its place in the foundry industry, and it is the author's opinion that it is rapidly finding this place. Some proponents recommend that radiography should be used as a routine inspection procedure for inspection of castings, but from experience the author believes that radiography should be used primarily as a tool for development of production practices, and that producers of castings who have used radiography concur in this opinion. The indiscriminate use of x-ray or radium is costly and is wasteful of time, materials and personnel.

As we have come to consider radiography, its use should be largely limited to the inspection of sample castings to determine the internal defects not visible on the surface, and this information used to correct the production practice so as to eliminate the defects found.

This procedure should be repeated until a sound casting is obtained. Periodic checks then should be made when the casting is put into production. The frequency of this checking and the thoroughness of its coverage can be gradually reduced as production proceeds and no trouble is experienced.

There may be certain extreme cases where the casting may be designed for such critical service that complete radiography of every casting produced would be justified. These cases are, in the author's opinion, very rare, and it goes without saying that in such cases the cost of the radiographic inspection must be passed along to the customer.

X-ray, of course, has its limitations. The thickness of the metal sections to be x-rayed are, of course, limited by the equipment available. The lower voltage machines around 220 kilovolts are limited to about 3 in. of steel; the larger machine, such as the 1000 kilovolt, can penetrate up to 7 in., while the 2000-kilovolt machine recently developed can penetrate up to 10 in. of steel.

Radiography

Radiography by gamma ray is not limited so sharply, its limitations being largely determined by the amount of radium and the time available. Another limitation of radiography is the size of defect found. It is generally conceded that the smallest defect that can be detected by x-ray or gamma ray is 2 per cent of the metal section. However, under ideal conditions, slightly better results can be obtained.

Another method of non-destructive casting inspection which has been widely accepted is magnetic particle testing. This method of testing has received much criticism and very stiff opposition in some quarters. Much of this criticism has, in the author's opinion, been deserved, for it is felt that much more has been expected of this test than it is capable of telling us. However, we do not mean to imply by this that magnetic particle testing does not have its proper place in modern inspection procedures.

Magnetic particle testing is limited to defects in the surface or defects relatively close to the surface of the casting. It is extremely sensitive to very small surface or subsurface cracks, and it is this characteristic that has been responsible for much of the criticism.

In the hands of inexperienced operators and in improper application, the patterns shown by magnetic particle testing may be made to look much worse than they really are. Those who have had experience with this tool will agree that it requires a well-trained and skilled operator to properly interpret the results.

Many castings are made today where magnetic particle testing is a valuable adjunct to the ordinary inspection methods. These are castings which are subject to high fatigue stresses. In castings designed for such service, it is imperative that the surface be free of all minute cracks or other imperfections which may be a focal point for stresses, thus causing early fatigue failure.

Much of the unpopularity of this type of inspection has been in its application to inspection of castings wherein the perfection demanded has not been justified by the end use of the casting inspected.

On the whole, it is felt that magnetic particle testing provides a valuable tool for better inspection of castings; it has a definite place in the modern and progressive foundry, for it helps to fill the gap between visual inspection and radiographic inspection.

The needs of war brought about many other changes in the foundry industry. Prominent among these is the widespread use of specially heat-treated alloy castings. This comparatively new foundry technique, to which many were introduced only since the beginning of the war period, involves several new testing and inspection techniques, among which is hardness testing.

Hardness testing of metals is, of course, not new. We used to think of hardness testing as applied only to small laboratory samples, but this new program of hardening large castings by liquid quenching made it necessary that we have some method of checking these heat-treating processes to make sure that the castings, as shipped, meet the specifications for hardness. For the most part, these hardness tests are made with a so-called portable Brinell tester.

This apparatus consists of a small fixture for holding a standard Brinell ball in contact with both the casting and a small bar of known hardness. The fixture is struck a sharp blow with a hammer, which produces simultaneously an impression in the bar and in the casting. The diameters of both of these impressions are measured. Knowing the hardness of the standard bar, the hardness of the casting can be calculated from the ratio of the impressions as measured.

This method of hardness measurement is, of course, subject to many errors, and under normal conditions is none too reliable for exacting work, yet it has been a definite help in obtaining castings of good quality and castings that meet customers' requirements.

Laboratory Tests

Often we do not think of our routine laboratory tests as being inspection procedures, but in reality they are a phase of inspection since they are made solely to insure the highest quality obtainable and to make certain that the product meets the customer's specifications.

The use of the metallurgical microscope for checking our heat-treating and melting processes is well established, and does not merit any lengthy discussion at this time other than to point out that it is an excellent example of laboratory equipment that is used to good advantage in the control of quality.

The tensile testing of steel has long since been a standard part of inspection procedure since it is universally required in practically all specifications. This method of testing has been quite highly developed for some time, and there has been very little added in late years except a few refinements in the equipment available. Some producers have been required to add stress-strain recorders to obtain certain data in connection with some alloy steel, but its application is still somewhat limited.

Impact testing was developed several years ago, but has never been so widely used until the requirements of production made it necessary. The use of some ordnance material in extremely cold climates has indicated that steel may have radically different properties at these low temperatures than was indicated by tests made at room temperatures.

From this has developed some new techniques for testing the metal at temperatures as low as 40° F. below zero. This program has shown many interesting things to date and holds promise of many other developments for the future.

One other phase of inspection that may well be presented for consideration is the use of quality control charts. This is a comparatively new development in inspection which the Army Ordnance Department has been instrumental in bringing before the industry.

This is a system of statistical treatment of inspection results which is kept in chart form. These charts are based upon certain mathematical laws of probability, and in the treatment of large bodies of inspection data present a very good picture of past performance. These laws of probability made it possible to predict with reasonable certainty what future performance should be.

If these charts indicate at any time that performance is not following the predicted pattern, then some point in the process has gone "haywire" and requires immediate attention. Oftentimes, definite trends in results, one way or another, can be detected before the process actually goes out of control and, if the investigation is prompt and thorough, the trouble often can be found and corrected before it is too late.

The subject of quality control charts is quite large. A thorough discussion would be beyond the scope of this paper. Experience along these lines has not been extensive, but we have made a small beginning in this application and are finding the results interesting and helpful.

In conclusion, the author wishes to express appreciation for the valuable counsel and advice given in the preparation of this paper by R. O. Tibbals, Chief Process Inspector at the East St. Louis Works of the American Steel Foundries.

Melting MAGNESIUM *Alloys*

By L. M. Nash, Production Manager and Metallurgist,
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DUE to the greatly increased demand for magnesium alloy castings for war purposes, and to the necessity for training new personnel quickly, there was a general pooling of knowledge by the magnesium industry. The result of this is that all phases of the handling of magnesium have been well covered by many of the trade publications and also by government sponsored research. However, a general review of the "melting process" step by step with emphasis on the important points may prove helpful.

At the present time there are three principal methods of melting magnesium:

1. The wet flux method for refining and casting.
2. The crucible method used in sand and large permanent molds.
3. The sulphur atmosphere method used only for low temperature work, such as die castings.

Wet Flux Method

The wet flux method is now used mostly for alloying and refining and as a holding furnace for crucible melting. This process consists of using a flux, composed chiefly of magnesium and sodium chlorides, which is very fluid and melts at temperatures several hundred degrees below the melting point of magnesium alloys.

The melt consists of about one-third flux, most of which stays at the bottom of the pot, with just a thin film of flux over the top of the metal and down the sides of the pot. Pouring is done from this pot by means of a bottom-pour hand ladle. The flux is swept from the top of the metal with a lip on the side of the ladle, and once a ladleful is removed the flux again covers the metal surface, keeping it completely protected from the atmosphere.

Because of the large amount of flux used and the design of the pot, which is roughly a half sphere, this is the best method yet developed for cleaning and refining magnesium.

• General pooling of knowledge and extensive research made possible the wartime production of magnesium alloy castings. Developments in magnesium foundry melting presented before Southern California Chapter of A.F.A., Oct. 12, 1945.

The flux can be stirred thoroughly through the metal and thus perform a very efficient job of removing dirt and oxides.

The presence of oil and paint will destroy the flux efficiency rather quickly, so that often it is more economical to remove excessive amounts of these impurities before melting. However, very dirty and badly oxidized scrap can be put into first class condition by this process. It was developed in this country by the Dow Chemical Co. and was the principal process used in magnesium melting until about 1937.

The greatest drawback to this method is that, unless extreme care is exercised by an experienced operator, it is very easy to dip flux out of the pot with the metal and leave traces of flux in the castings poured. As the flux has a great affinity for moisture, it will show up in the castings as grayish-white spots in a few days, or even overnight in a humid atmosphere.

These spots continue to grow in size as corrosion progresses, and usually cannot be removed but continue to re-appear no matter how often the casting is re-sandblasted and pickled, thus making the casting unfit for use. This method is being used successfully in production foundries where the molds can be conveyed to the furnaces, but is difficult to use in a jobbing shop as there is no way to transport or pour more metal than can be carried in a hand ladle.

Crucible Method

Because almost any amount of metal can be prepared and poured from the crucible, this method has become that most commonly used by the foundry today. This process was first developed in Germany but, due to patent and development difficulties, did not get much of a start in this country until 1935.

The crucible melting method consists of a batch process somewhat similar to that used with brass, where the metal is melted in and poured from the same crucible. With magnesium alloys the metal is melted with a small amount of flux in a welded steel crucible.

Because there is a very slight iron pick-up, which lowers the corrosion resistance, steel crucibles are not the perfect melting medium, but all other types are bonded with clays containing silicon, which will alloy with magnesium. The only exception is the silicon-carbide crucible, and present work being done indicates this crucible as a possibility.

Preventing Oxidation

The foundry practice used for magnesium alloys is, in general, the same as that used for any other metal. The main difference in the practice is the necessity for preventing oxidation. The word oxidation is used here as a general term because magnesium not only combines readily with the oxygen in the air, but almost as readily with the nitrogen.

It is this chemical activity that has to be guarded against if good castings are to be produced. Inhibiting agents must be added to the core and molding sands, fluxes must be used in melting and an inhibitor must be dusted on the metal stream during pouring. Overlooking this basic fact causes most of the trouble met with in magnesium foundries.

If the practice is to melt the metal directly in the crucible, the first point to be watched is the condition of the scrap. One of the main advantages of the crucible method is the minimum amount of flux used.

All scrap should be sandblasted

to remove as much of the surface oxide and dirt as possible, and scrap that cannot be properly cleaned should be separated and melted only by the wet flux method and poured into ingots for future use, or be discarded altogether. A crucible melt using 100 per cent scrap can be just as good or better than one made with virgin ingot provided that sufficient care be taken to see that the scrap is clean.

Silicon Content

All traces of sand must be removed from the scrap, regardless of the melting method used. Magnesium combines quite readily with silicon, and a relatively small amount of silicon produces brittleness and also interferes with proper heat treatment. All specifications for magnesium alloys allow a maximum of 0.3 per cent of silicon, and this is two or three times the amount that will be present if the scrap has been kept clean. Silicon can be held to about 0.05 to 0.06 per cent.

During the melting operation, care must be taken to keep the metal covered with flux as it melts down. Any oxides produced in melting increase the amount of time and labor needed to clean the metal. If melting is carelessly done, it may be impossible to really clean the metal.

One form of crucible melting practice consists of a double fluxing operation, where a relatively wet flux is used to first clean the metal and a dryer flux then used for protection. This can be a very good procedure to clean dirty metal, but again it increases the danger of flux inclusions if too much wet flux is used. In the author's opinion, it is safer and easier to take a little more care before and during the melting to make this step unnecessary.

Stirring the Melt

The next step in melting is the stirring operation. The temperature at which this is done is not very critical, but it seems to work best at temperatures of 1350° to 1425° F.

These temperatures are about as high as can be used if excessive oxidation is to be prevented during stirring. Inasmuch as the purpose of stirring is to remove oxide, it would be poor practice to perform the operation at a temperature which would produce more oxide.

The stirring is done with an iron rod, preferably square, and long enough to reach the bottom of the pot. The operation consists of stirring the metal rather vigorously with a circular motion so as to make the metal in the pot actually rotate. This is accompanied by an occasional sprinkling of flux to keep a flux cover on the surface of the metal to trap the oxides.

This operation takes from 1 to 5 min., depending upon how carefully the operation has been conducted up to this point. When properly done, the metal will present a silvery, bright, mirrorlike surface when skimmed. If improperly done, the surface will have the appearance of being pimply, due to the presence of small oxide particles floating near the surface. If the metal is poured in this condition it will be of poor quality and, as the oxide particles left in the melt are partially coated with flux, they will produce flux spots on the castings.

The mechanics of the stirring operation seem to be twofold:

1. Flux is stirred into the melt where it can come into contact with the dirt and oxide particles, and after these particles become coated with flux they no longer hang in suspension in the melt but sink to the bottom or float to the top, depending upon their specific gravity.
2. Centrifical force set up by the rotary motion probably forces some of the heavier particles to the crucible wall, where they cling to the flux left on the wall during melting, and the lighter particles move toward the center where they are trapped in the flux added in stirring and then rise to the surface when stirring stops.

After stirring has been completed, the material accumulated on the surface is removed with a skimmer and a new light dusting of flux is added. As this entire operation should not take over 3 or 4 min., it usually is unnecessary to interrupt the heating of the melt.

Superheating the Melt

The next step is to heat the melt to a temperature of at least 1600° F. for not less than 20 min., or as high as 1700° F. for approximately 10 min. This superheating procedure produces a finer grain size in the melt and, as grain size and strength are related, it is important to produce as fine a grain as is possible.

After superheating the metal should be held at a temperature of not less than 1450° F. until it is ready to pour, and then cooled as quickly as possible to pouring temperature. This is because the effect of superheating is lost quite rapidly if the metal is held for a period of time at a lower temperature. The next point to watch in order to help prevent having flux inclusions in the castings is that no flux should be added to the melt for at least 10 min. before pouring.

The flux when first added is only slight wet, and in this state it can easily flow with the metal into the mold. After heating for a few minutes, the flux becomes thick and sticky and will cling to the crucible. On the surface of the metal when it is exposed to the air it forms a hard crust. This hard crust will protect the metal perfectly, and can be removed or pushed out of the way just before pouring.

Only the dusting agent should be used to prevent burning from then until pouring is completed. Also, all accumulations of flux on the pouring lip and rim and ears of the crucible should be brushed off. The total amount of flux necessary to complete the melting operation should not be more than 2 or 3 per cent by weight of the metal melted.

Gas Causes Porosity

Normally, magnesium dissolves very little gas, and it is only recently that it was found that hydrogen does dissolve in it. During the past 3 years much work has been done on this subject, and it has been proven that the presence of gas has a very pronounced effect on the amount of porosity present in magnesium alloy sand castings, especially in heavy sections.

Much of this gas comes from moisture. Because of this fact it is essential that all materials should be as dry as possible. The scrap, ingot, and tools should be preheated on the top of the furnace even when they seem to be dry, because the amount of moisture necessary to cause gas would not be as much as is needed to blow metal out of the crucible.

The most difficult material to keep dry is the flux. As it is composed largely of chlorides, it can contain enough moisture to cause considerable gas trouble without appearing

to be even damp. This means that flux drums should be kept covered.

Much work has been done on methods of gas removal and on a more positive method of grain refinement.

A number of materials, such as some of the alkaline earths and some of the carbides and graphite, do give results when added to the melt, but so far none of them has proved to give consistent results.

Great promise has been found in chlorine gas bubbled through carbon tetrachloride and then passed through the melt. This process, when done in a silicon-carbide crucible, has proved its ability to clean, degas and give grain refinement all in one operation. However, at the present time not much is known about this process and, as both chlorine and carbon tetrachloride are toxic and corrosive chemicals, their handling by the average person is somewhat dangerous unless proper precautions are observed. The present practice gives good results and should be followed until the chlorine-carbon tetrachloride method has been thoroughly studied.

Conclusion

In closing, it would be well to mention two points on safe handling. All crucibles should be gone over between heats with a ball peen hammer to make sure that there are no thin spots or cracked welds. A small leak of magnesium into the furnace produces such an intense heat that it will burn the whole bottom out of the crucible, resulting in a hazardous magnesium fire. Also, all furnaces should be kept clean, as the iron scale from the crucibles produces a thermite reaction with magnesium when hot and can cause a violent and explosive reaction.

Observance of these basic melting practices will pay dividends in better castings.

Effect of Table Rise (Strain Rate) on Hot Strength of Bentonite Bonded Sands

• Reproducibility of hot strength tests of foundry molding materials, which may develop different characteristics at various points of the test temperature range, may be secured by selection of a predetermined strain rate value.

By H. W. Dietert, President,
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HOT strength tests on foundry molding materials are conducted under a very wide temperature range, for example, from 500 to 2500° F. Within this temperature range, the test specimen of the material under test may be a hard brittle substance at the lower temperature and a very plastic material at the higher temperature.

The problem presents itself immediately whether a constant rate of load (stress), or a constant rate of table rise (strain), should be used during the application of the load. The author believes that a constant rate of loading (stress) which would be applicable for both the very brittle and plastic materials is impracticable.

Nearly all hot strength tests made to date have been made under conditions of constant rate of table rise (strain). The rate of table rise (strain) should be selected at a predetermined value; for example, 1-in. per min. when reproducible test results are desired.

Test Conditions

It is plausible that, at some value of table rise (strain) the maximum number of desirable test conditions would be obtained. To obtain a partial answer to this important problem, hot strength tests were made under varying table rise.

Green sand specimens of the 1⅛ x 2-in. size were used, consisting of a sand composed of No. 17 washed and dried sand bonded with 5 per cent western bentonite and tempered with 2.5 per cent moisture. The sand was prepared in an 18-in. diameter laboratory muller, screened through No. 6 mesh sieve after mixing and sealed in an air-tight container, allowing 30 min. tempering time before using the material.

Hot strength determinations were made at temperatures of 500, 1000, 1500, 2000 and 2500° F. in a 1940 model dilatometer equipped with a 2-in. I.D. furnace and an adjustable volume hydraulic pump with motor drive.

The green sand specimens were allowed to soak for a period of 12 min. before applying the load. The current input into the furnace was such as to obtain a furnace temperature recovery in 2 min.

Table 1 shows hot strength in psi. as obtained for table rise (rate of strain) from 0.5 to 1.25 in. per min. All test readings were recorded and only two readings in this group of tests were rejected. Good reproducibility was obtained at all rates of table rise. A graphical presentation of this data is shown in Fig. 1.

In general, there is an increase

Table 1

THE EFFECT OF TABLE RISE (STRAIN RATE) ON HOT STRENGTH (PSI.) OF BENTONITE BONDED SANDS

	Hot Strength (psi.) at Temperatures				
	500° F.	*1000° F.*	*1500° F.*	*2000° F.*	*2500° F.*
	Rate of Table Rise—0.5 in. per min.				
	94*	100*	496	80	4
	70	80	437	80	4
	68	86	420	76	4½
	78	76	446	....	4
		86	454	....	.....
Avg.	72	82	450	79	4
	Rate of Table Rise—0.75 in. per min.				
			493	98	
	100	87	527	90	4½
	90	94	462	104	4½
	88	83	532	103	4½
				90	.....
Avg.	93	88	503	97	4½
	Rate of Table Rise—1.0 in. per min.				
	83		482	105	
	100	90	524	100	4+
	87	94	477	111	5
		96	512	105	5
Avg.	90	93	499	105	5
	Rate of Table Rise—1.25 in. per min.				
	112	103	512	115	4
	96	110	520	110	4
	96	110	510	103	4
	96	108	532		3
Avg.	100	105	518	109	4

*Readings rejected.

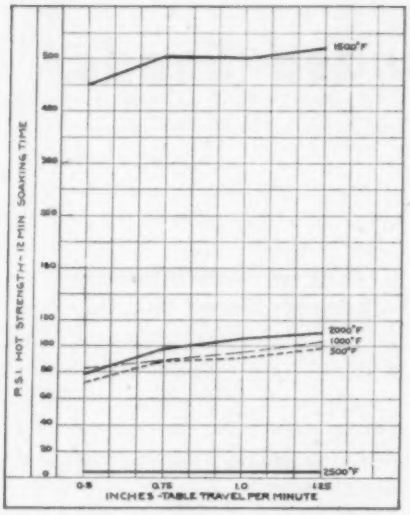

Fig. 1—Hot strength of green sand specimens plotted against table rise.

in hot strength as the table rise (strain) is increased from 0.5 to 1.25 in. per min. with the exception of the hot strength for the 2500° F. range. For table rise from 0.5 to 0.75 in. per min., there is a marked increase in hot strength for temperatures to 500, 1000, 1500 and 2000° F.

From this data, a table rise from 0.75 to 1.0 in. per min. under no load should be chosen to obtain a table rise rate (strain rate) which produces the least effect on hot strength readings.

For tests where data is interchanged among certain investigators, a table rise of 1.0 in. has been chosen and seems to meet conditions such as:

1. Not too time consuming.
2. Not too rapid to make it difficult to take psi. readings.
3. Suitable for hot deformation readings.
4. Adaptable to both brittle and plastic materials.
5. Suitable to obtain reproducible hot strength readings.

The data presented herein is only the beginning, and much additional work must be done to obtain complete information before further standardization on the rate of table rise may be accomplished.

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